JOURNAL of THE IRON AND STEEL INSTITUTE

VOL. 158 PART 4

APRIL 1948

Editor
K. HEADLAM-MORLEY

Managing Editor
E. R. MORT, B.Sc., F.I.M.

Technical Editor
A. E. CHATTIN, B.Sc., A.R.I.C., F.I.M.

Assistant Editor
C. R. HARMAN, B.Sc.(Eng.)

PUBLISHED ON THE 20th EACH MONTH

Editorial contents copyright by THE IRON AND STEEL INSTITUTE

SUBSCRIPTIONS

Members : Free
Extra Copies 7s. 6d. each

Non-Members : £5.0.0 per annum
Single Copies 10s. each

EDITORIAL AND ADVERTISEMENT OFFICES

4, Grosvenor Gardens, London, S.W.1

Telephone : SLOane 0061. Telegrams : Irosamente, Sowest, London

CONTENTS

PROCEEDINGS OF THE INSTITUTE

Report of Council for 1947 417

IRON AND STEEL INSTITUTE PAPERS

"The Carbides in Iron-Carbon-Silicon Alloys and Cast Irons" *by D. Marles* .. 433

DISCUSSION ON PAPERS

Discussion on Hydrogen in Steel 437
Discussion on the Fluidity of Steel 448
Discussion on Carbon Removal by Oxidation 451
Discussion on Gas-Producer Practice 456
Author's Reply to Discussion on Creep Tests.. 462

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

First Report of the Methods of Testing (Corrosion) Sub-Committee 463
"Note on Further Work on the Phosphorus Reaction in Basic Steelmaking" *by P. Vajragupta* 494
"Note on a New Method for Checking the Profile of Wire-Drawing Dies" *by J. G. Wistreich* 496

IRON AND STEELWORKS ENGINEERING

"Electronic and Servo Electronic Controls and their Application to the Iron and Steel Industry" *by W. G. Thompson* 497
"The Maintenance of Electrical Machinery in Iron and Steel Works" *by G. S. Martin and M. Y. Harvey* 510

NEWS

The Iron and Steel Institute .. 521
Annual General Meeting .. 521
Hatfield Memorial Lecture .. 521
Meeting on Protection of Steel 521
Awards 521
Seventy-Five Years Ago .. 522
News of Members 522
Contributors to the Journal.. 523
British Iron and Steel Research Association .. 524
Iron and Steel Engineers Group 524
News of Science and Industry 524
Memoirs 525
Diary 526
Translation Service 526

ABSTRACTS and BOOK NOTICES

Contents 527
Abstracts 527–543
Book Notices 543
New Publications 544

NOTE: The Institute as a body is not responsible for statements made, or opinions expressed, in papers, articles or discussion appearing in the Journal of The Iron and Steel Institute.

ENGLISH STEEL CORPORATION LTD

VICKERS WORKS SHEFFIELD

PROFESSOR ROBERT F. MEHL

ROBERT FRANKLIN MEHL was born in Lancaster, Pa., U.S.A., on 30th March, 1898. He received his early technical training at Franklin and Marshall College, Lancaster, Pa., where he graduated as B.S. in 1919 ; in 1924 he gained the degree of Ph.D. at Princeton University.

Professor Mehl was a Proctor Fellow in Chemistry at Princeton University (1922–1923) ; he started his professional career as Head of the Department of Chemistry at Juniata College (1923–1925), and followed this with a period as a National Research Fellow at Harvard University (1925–1927). He next took the position of Superintendent of the Division of Physical Metallurgy at the Naval Research Laboratory, Washington, D.C. (1927–1931), inaugurating this division, and then became Assistant Director of the Research Laboratories of the American Rolling Mill Company, Middletown, Ohio In 1932 he became Director of the Metals Research Laboratory and Professor of Metallurgy at the Carnegie Institute of Technology, Pittsburgh, Pa., and in 1935 was made Head of the Department of Metallurgical Engineering in the same Institute ; these positions he continues to hold.

Professor Mehl has published about a hundred papers on the constitution of alloys, crystal structure, radiography, the electron microscope, the properties of forging steels, general metallurgy, theory of age-hardening, heat-treatment of steel, etc. He translated Gustav Tammann's book on " The States of Aggregation " (1925) and published his own book on the " Metallurgy of Iron and Steel " (in Portuguese) in Sao Paulo in 1944. His " History of Physical Metallurgy " was issued in 1948 by the American Institute of Mining and Metallurgical Engineers.

Professor Mehl has received many honours. He holds honorary degrees of Franklin and Marshall College (1938), Sao Paulo University (1944), and Stevens Institute of Technology (1944), and, among others, has received the John Scott Medal, awarded by the Directors of the Board of City Trusts, City of Philadelphia (1934), the Howe Medal of the American Society for Metals (1939) and the James Douglas Gold Medal of the American Institute of Mining and Metallurgical Engineers (1945). He has delivered many important lectures, such as the Campbell (1941) and the Sauveur (1940 and 1943) Lectures of the American Society for Metals, the Annual Lecture of the Institute of Metals Division, American Institute of Mining and Metallurgical Engineers (1936), and the Priestley Lectures at the Pennsylvania State College (1938).

Professor Mehl is a member of a number of technical and advisory committees associated with the U.S.A. Government and with technical and scientific societies. During the second world war he was an attaché at the U.S. Embassy in London (1945), with the similated rank of Brigadier General.

Professor R. F. Mehl

Third Hatfield Memorial Lecturer, 1948

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

REPORT OF COUNCIL FOR 1947

THE Council submit this, their Annual Report and Statement of Accounts for the year 1947, to Members for their approval at the Seventy-Ninth Annual General Meeting of The Iron and Steel Institute. In some sections information later than 31st December, 1947, has been included.

The following are the more important developments which took place during the year. Collaboration with the British Iron and Steel Research Association was extended, and is believed now to be firmly established in the mutual interests of both organizations. The *Journal* in its new monthly form successfully completed its first year of publication in spite of restrictions on the consumption of paper and other serious difficulties in publishing; numerous expressions of appreciation of the contents and appearance were received. Arrangements for separating the staffs and secretaryships of the Institute and the Institute of Metals were carried through, and very friendly relations maintained with that Institute and with the Institution of Metallurgists. Collaboration with Affiliated Local Societies and important metallurgical societies overseas was extended to additional societies. The post-war programme for reorganizing the Library and Information Services was continued. A Special Summer Meeting in Switzerland was organized in addition to the Annual and Autumn General Meetings; several special meetings were held, and the programme of meetings of the Engineers Group was successfully extended. Progress was made in educational activities. Membership reached a new record figure.

ROLL OF THE INSTITUTE

Membership at the end of the year totalled 4522, an increase of 478, or 12% over the record figure of the previous year. Particulars are given in Tables I and II, and in Fig. 1.

The continued growth in both the home and overseas membership is satisfactory. The number of Home Members (including Associates) increased by 11% and the number of Overseas Members by 14%; the latter numbered 1006, or 22% of the total. The number of Associates was 740, an increase of 23%; of these 57% were members also of the Institute of Metals. The total figures included 995 Members, 420 Student Members, and 3 Associates of the Institute of Metals (a total of 1418) and 325 Fellows, 312 Associates, and 153

Table I

MEMBERSHIP OF THE IRON AND STEEL INSTITUTE AT 31ST DECEMBER, 1947

	Ordinary Membership		Joint Membership with—								Total Membership		Grand Totals
			Institute of Metals		Institution of Metallurgists		Both Institute and Institution		Totals				
	Home	Overseas	Home	Overseas	Home	Overseas	Home	Overseas	Home	Overseas	Home	Overseas	
Patron	1	..	..	..	..	..	..	..	..	..	1	..	1
Members :													
Ordinary	1738	642	423	233	299	20	306	19	1028	272	2766	914	3680
Hon. Vice-Presidents	8	4	1	1	..	..	..	..	1	1	9	5	14
Honorary Members ..	2	4	2	..	..	..	..	..	2	..	4	4	8
Non-paying Members	6	..	..	..	..	..	..	..	..	..	6	..	6
Life Members	40	18	4	5	5	..	1	..	10	5	50	23	73
Totals (Members) ..	1795	668	430	239	304	20	307	19	1041	278	2836	946	3782
Associates	227	39	314	20	50	1	89	..	453	21	680	60	740
Totals (both classes)	2022	707	744	259	354	21	396	19	1494	299	3516	1006	4522

Table II
HOME AND OVERSEAS MEMBERSHIP, 1941 TO 1947

At 31st December:	1941		1942		1943		1944		1945		1946		1947	
	Class	Totals	Class	Totals	Class	Totals	Class	Totals	Class	Totals	Class	Totals	Class	Totals
Patron	1		1		1		1		1		1		1	
		1		1		1		1		1		1		1
Hon., etc., Members :														
Home	5		5		5		6		10		10		13	
Overseas ..	10		9		7		7		6		8		9	
		15		14		12		13		16		18		22
Life Members :														
Home	40		39		43		44		47		47		50	
Overseas ..	20		21		21		21		20		20		23	
		60		60		64		65		67		67		73
Ordinary Members :														
Home	1698		1753		1883		2017		2180		2540		2772	
Overseas ..	515		460		471		465		556		816		914	
		2213		2213		2354		2482		2736		3356		3686
Associates :														
Home	227		261		332		438		494		560		680	
Overseas ..	35		34		37		35		42		42		60	
		262		295		369		473		536		602		740
Totals :														
Home	1971		2059		2264		2506		2732		3158		3516	
Overseas ..	580		524		536		528		624		886		1006	
Total Membership		2551		2583		2800		3034		3356		4044		4522

Licentiates of the Institution of Metallurgists (a total of 790).

The current Roll of Members does not include 30 Members and 17 Associates who have been placed on the military service suspense list.

Thirty-seven deaths were reported during the year and 90 Members and Associates resigned; 35 were struck off the List of Members owing to non-payment of subscriptions. None were transferred to the military service suspense list. Seven hundred and five Members and Associates were newly elected or reinstated.

OBITUARY

The Council regret to record the deaths of the following 31 Members which occurred during 1947 :

Buchanan, W. (Darlington) ...	29th May
Castle, G. C. (London)	?
Clark, N. A. (London)	20th November
Clarke, F. P. (Middleton St. George, Co. Durham)	21st June
Cooper, F. W. (Wrexham) ...	28th April
Cowper, G. (London)	9th October
Davies, J. P. (Dowlais, Glam.) ...	?
Donaldson, Dr. J. W. (Greenock, Renfrewshire)	12th January
Dowding, G. F. (London) ...	21st March
Dutton, J. P. O. (London) ...	9th March
Foster-Smith, J. (London) ...	24th January
Garner, J. R. (Sheffield) ...	21st September
Goldsborough, W. (Irlam, near Manchester)	13th January
Graham, C. S. (Scunthorpe) ...	12th April
Hewitt, D. H. (London) ...	25th August
Horne, J. A. (Sheffield)	16th August
Jay, Dr. A. H. (Sheffield)... ...	22nd February
Jobson, J. F. (Philadelphia, Pa., U.S.A.)	27th April
Jollie, A., sen. (Sheffield) ...	27th April
Jones, G. (Pontardawe, Glam.) ...	1st February
Lee, A. W. (Scunthorpe) ...	3rd July
Lewis, G. (Wolverhampton) ...	7th August
Luckman, Captain J. F. (Hay Mills, near Birmingham) ...	7th October
McQuistan, A. N. (Middlesbrough)	21st June
Moore, S. (Derby)	7th February
Primrose, J. S. G. (Birmingham)	2nd October
Talbot, B. (Northallerton, Yorks.)	16th December
Toft, J. L. (Coniston, near Manchester)	15th September
Trinham, Col. J. S. (Dudley, Worcs.)	25th August
Troughton, E. R. (London) ...	8th May

The deaths of the following 5 Members took place before 1947, but were not previously reported :

Bannister, J. B. (Scunthorpe) ...	3rd October, 1946
Harris, H. E. (Oldham, Lancs.) ...	22nd September, 1946
Hoskison, T. (Wolverhampton, Staffs.)	10th December, 1946
Ibbotson, E. C. (Bournemouth)...	16th January, 1942
Larkin, G. F. (Newark-on-Trent, Notts.)	7th December, 1946
Wotton, J. E. (Pontypool, Mon.)	9th November, 1946

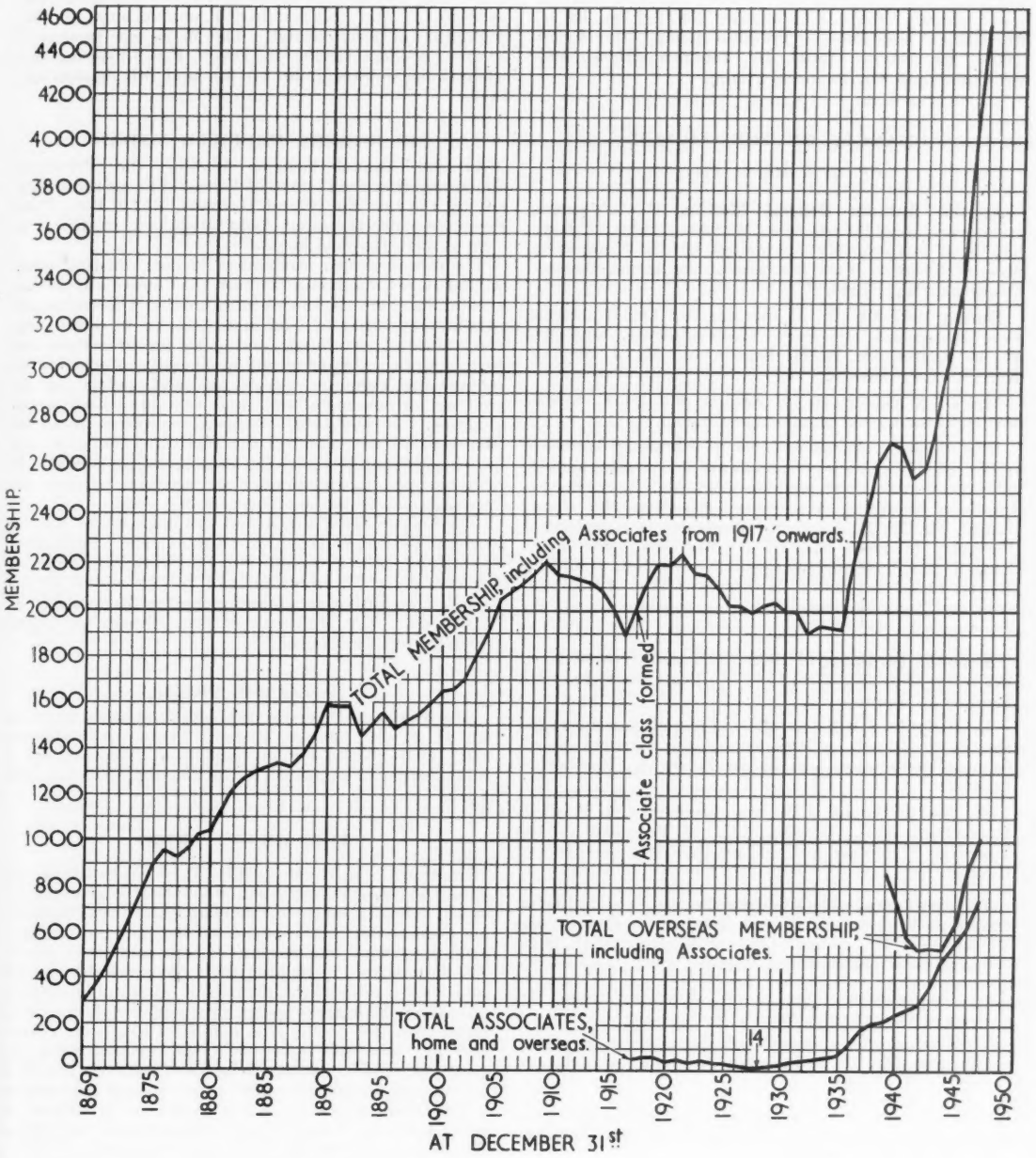


Fig. 1—Variation in membership since the foundation of the Institute in 1869

Mr. Benjamin Talbot was a Past-President of the Institute, and had been a Member since 1900. Dr. Donaldson, elected in 1915, was at the time of his death President of the West of Scotland Iron and Steel Institute and an Honorary Member of Council of The Iron and Steel Institute. Eight of the deceased Members had been connected with the Institute for forty years or more, namely, Captain Luckman (elected in 1898), Mr. Cooper and Colonel Trinham (1902), Mr. Lewis (1903), Mr. Davies (1904), Mr. Ibbotson (1905), and Mr. Clarke and Mr. Primrose (1908).

CHANGES ON THE COUNCIL

(To 17th March, 1948)

At the Autumn General Meeting the President announced that Sir Andrew McCance, D.Sc., F.R.S., had been unanimously nominated by the Council to become President of the Institute at the Annual General Meeting in May, 1948.

During 1947 Mr. W. J. Dawson and Dr. R. Durrer were nominated Honorary Vice-Presidents, and Mr. W. B. Baxter, Mr. H. H. Burton and Mr. J. Sinclair Kerr, Vice-Presidents.

Mr. D. A. Oliver, Mr. F. Saniter and Dr. C. Sykes, F.R.S., were elected Members of Council.

The following agreed to serve as Honorary Members of Council during their presidencies of the societies named, in succession to their predecessors: Mr. E. A. Davies (Swansea Metallurgical Society, following Mr. G. J. Jones), Mr. W. M. Larke (Staffordshire Iron and Steel Institute, following Mr. G. B. Morrison), Mr. T. F. Russell (Sheffield Metallurgical Association, following Mr. H. Bull), and Mr. T. M. Service (West of Scotland Iron and Steel Institute, following the late Dr. J. W. Donaldson).

Since the beginning of 1948 Mr. T. Jolly (Guest Keen Baldwins Iron and Steel Co., Ltd.) has been elected a Member of Council.

Dr. C. Sykes, F.R.S. (Member of Council), has succeeded Mr. T. F. Russell as President of the Sheffield Metallurgical Association and as an Honorary Member of Council.

Sir Arthur Smout, J.P., has succeeded Col. P. G. J. Gueterbock, C.B., D.S.O., M.C., as President of the Institute of Metals and as an Honorary Member of Council.

In accordance with Bye-Law No. 10, the following names of Vice-Presidents and Members of Council due to retire at the Annual General Meeting, 1948, were announced at the Autumn Meeting, 1947:

Vice-Presidents—Mr. J. R. Menzies-Wilson, Mr. James Mitchell, and Mr. R. Mather.

Members of Council—Mr. I. F. L. Elliot, Mr. C. R. Wheeler, Mr. E. F. Law, Dr. C. Sykes, F.R.S., and Mr. D. A. Oliver.

No other Members having been nominated up to one month before the Annual Meeting, the retiring Members are presented for re-election.

BESSEMER GOLD MEDALS

Two Bessemer Gold Medals were awarded in 1947. The first was presented at the Annual General Meeting to Sir William Larke, K.B.E., the recently retired Director of the British Iron and Steel Federation, in recognition of his distinguished services in promoting research in the iron and steel industries.

A special Medal was presented to Dr. Magnus Tigerschiöld, Director of Research, Jernkontoret (Swedish Ironmasters' Association), Stockholm, in recognition of his distinguished services to the iron and steel industry of Sweden, and as part of the Institute's tribute on the occasion of the two-hundredth anniversary of the foundation of Jernkontoret. The Medal was presented by the President (Dr. C. H. Desch, F.R.S.) during the celebrations in Stockholm on 5th and 6th September, 1947.

SIR ROBERT HADFIELD MEDAL

At the Annual General Meeting the President announced that the Council had decided to use the legacy left by the late Sir Robert Hadfield, Bt., F.R.S., Past President and Bessemer Gold Medallist, to found a "Sir Robert Hadfield Medal."

The medal, struck in stainless or heat-resisting steel, will be awarded annually to mark the Council's appreciation of meritorious service in improving the technique of the production of iron and steel, or in developing the science of metallurgy, and as an encouragement for further work; the terms will be liberally interpreted to include fuel economy, refractories, and engineering, as well as ferrous metallurgy and iron and steel works practice. At the time of award recipients must be Members (of any class) of the Institute, and must not previously have received the Bessemer Gold Medal. It will be open to the Council on occasion to give the Medal jointly to two recipients in one year.

The first award of this medal was made at the Annual General Meeting to Dr. J. H. Chesters (The United Steel Companies, Ltd.) in recognition of his work on refractories for the use of the iron and steel industries and for his share as co-author in preparing Special Report No. 37 (1946) on "The Influence of Port Design on Open-Hearth Furnace Flames."

WILLIAMS PRIZE

The Williams Prize for 1947 (£100) was awarded to Mr. R. Fowler (Messrs. Richard Thomas & Baldwins, Ltd., Ebbw Vale) for his paper on "Blowing-out a Blast-Furnace," published in the *Journal*, 1947, vol. 155. April.

THE ABLETT PRIZE

Captain C. A. Ablett, O.B.E., B.Sc., M.Inst.C.E., has agreed to renew his Prize of £50. It will be available for award annually, on the recommendation of the Engineering Committee, to the author of a paper on a subject connected with engineering in iron and steel works. The Committee, in making their recommendation, will take into consideration all papers on suitable subjects published during the year in the *Journal*, including those presented to the Iron and Steel Engineers Group, and will also take account of the authors' ages and positions, so as to give due weight to the donor's intention to encourage younger engineers in iron and steel works.

The First Ablett Prize was gained by H. Escher for his paper on "Ten Years' Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia." The Prize was not awarded during the war.

ANDREW CARNEGIE MEDALS

No Andrew Carnegie Medals were awarded during 1947.

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS

During the year arrangements were made to extend the scope of grants from the Andrew Carnegie Research Fund. While research grants tenable in the recipients' own country will continue to be awarded, the Council are prepared to receive applications for one or two Andrew Carnegie Travelling Scholarships each year; these will usually be tenable for one year, and are intended to assist recipients to conduct researches outside their own countries.

The Travelling Scholarships will normally be of the order of £500, but smaller or greater sums may be given, the amount depending on the circumstances of each case. The amounts awarded for ordinary Andrew Carnegie Research Grants will also be somewhat increased, but they will not normally exceed £250 in a year, and the usual range is from £50 to £200.

The following two ordinary Research Grants were awarded:

G. L. EVANS (Swansea): £100 for a research on the equilibria of the sulphur reactions occurring in steelmaking.

ROBERT GUENOT (Sheffield): £200 for a research on the electrical properties of cold-worked metals and alloys.

MOND NICKEL FELLOWSHIPS IN METALLURGY

In April, 1947, the Mond Nickel Fellowships Committee was set up for awarding and administering the Fellowships. The Committee consists of representatives of the four Institutes to whom the funds were presented by the Mond Nickel Co., Ltd., together with a representative of the Company. The Iron and Steel Institute agreed to provide secretarial services for the Committee. Conditions of awards were drawn up and were printed on p. 123 of the May, 1947, issue of the *Journal* (vol. 156). Approximately forty applications were received.

The Committee decided to make the following awards for 1947:

L. H. WALKER (Reynolds Tube Co., Ltd.): To study the methods of application of group industrial research, particularly in relation to the fabrication of light metals. (Up to a maximum of £850.)

D. R. G. DAVIES (Messrs. Richard Thomas & Baldwins, Ltd.): To study the application of statistical methods to plant metallurgy and management problems, with particular reference to the steel industry. (Up to a maximum of £850.)

MEETINGS

Annual General Meeting

Technical Sessions—The Annual Meeting was held on Wednesday, 14th May, 1947, at the offices of the Institute, 4, Grosvenor Gardens, London, S.W.1 (sessions at 10.0 A.M. and 2.15 P.M.), and on Thursday and Friday, 15th and 16th May, 1947, in the Lecture Theatre of The Institution of Civil Engineers, Great George Street, London, S.W.1 (sessions at 9.55 A.M. and 2.30 P.M. on the Thursday and at 10.30 A.M. on the Friday). The President (Dr. C. H. Desch, F.R.S.) was in the Chair.

The whole of the Wednesday was devoted to the discussion of a "Symposium on the Hardenability of Steel" (Special Report No. 36); at the other three sessions twelve papers were discussed. (For the Second Hatfield Memorial Lecture, *see* p. 422.)

Buffet lunches were provided at the Institute's offices on the Wednesday and in the North Hall, Church House, Great Smith Street, London, S.W.1, on the Thursday.

Members' Dinner—A Dinner for Members and their guests was held at the Connaught Rooms, Great Queen Street, London, W.C.2, on Thursday, 15th May, at 7.15 P.M. The President (Dr. C. H. Desch, F.R.S.) was in the Chair. Nearly five hundred Members and guests were present.

Summer Meeting in Switzerland

A special Summer Meeting of the Institute was held in Zürich, Switzerland, on Thursday and Friday, 10th and 11th July, 1947, the arrangements being made in conjunction with a Swiss Reception Committee, of which Professor Dr. R. Durrer (Hon. Vice-President) was the Chairman. At the kind invitation of Dr. A. Rohn, President of the Schweizerischer Schulrat, the sessions took place in the Auditorium Maximum of the Eidgenössiche Technische Hochschule, commencing at 9.30 A.M. on both days and ending about 12.30 P.M. The President of the Institute (Dr. C. H. Desch, F.R.S.) was in the Chair. Nine papers were discussed; three others which had been prepared specially for the Meeting were also published in the *Journal*.

During their stay in Zürich, Members and their Ladies had the opportunity of visiting numerous works and beauty spots, in the more immediate neighbourhood and at Solothurn and Schaffhausen. Subsequently the party broke into two groups, one of which visited Interlaken and Montreux before returning home, while the other went to Geneva to visit several works there and also the hydro-electric metallurgical plant of the Société d'Electro-Chimie, d'Electro-Métallurgie et des Aciéries Electriques d'Ugine at Ugine in Haute-Savoie, France.

Autumn General Meeting

The Autumn Meeting was held at the offices of the Institute, on Wednesday and Thursday, 12th and 13th November, 1947, under the Chairmanship of the President (Dr. C. H. Desch, F.R.S.). The sessions started at 10.0 A.M. on both days and at 2.30 P.M. on the first day. A buffet lunch was available to Members in the Library of the Institute. Twelve papers were presented for discussion.

Special Meetings

Symposium on Powder Metallurgy—A Symposium on Powder Metallurgy was held at The Institution of Civil Engineers, Great George Street, London, S.W.1, on Wednesday afternoon (at 2.15 P.M.) and Thursday (10.0 A.M. and 2.15 P.M.), 18th and 19th June, 1947; Members of the Institute of Metals, of the Institutions of Mechanical, Electrical, Production, and Automobile Engineers and of the Society of Chemical Industry were invited to be present. On the Wednesday, Mr. D. A. Oliver took the Chair in the unavoidable absence of the President, while on Thursday, Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C. (President of the Institute of Metals), and Lieut.-Colonel Lord Dudley Gordon, D.S.O. (President of the Institution of Mechanical Engineers), presided at the morning and afternoon sessions.

The Symposium comprised twenty-eight papers, divided into six groups, each of which was presented for discussion by a rapporteur.

An exhibition of powder-metallurgy products was displayed in a room adjacent to the Lecture Theatre, and on the Thursday a buffet lunch was available to Members in the Library of the Central Hall, Westminster

The Protection of Iron and Steel Against Corrosion—A Meeting to discuss this subject was held at the offices of the Institute on Thursday, 26th June, 1947, at 2.30 P.M. Mr. T. M. Herbert, Deputy Chairman of the Corrosion Committee and Chairman of the Protective Coatings Sub-Committee of the British Iron and Steel Research Association, presided.

Invitations to attend the Meeting were sent to a number of other societies as well as to firms and individuals; the attendance was good and the discussion interesting.

Special Report No. 31, "The Effect of Different Methods of Pre-Treating Iron and Steel Before Painting," by F. Fancutt, and a paper on "The Protection of Iron and Steel by Metallic Coatings," by J. C. Hudson and T. A. Banfield, were discussed.

SECOND HATFIELD MEMORIAL LECTURE

The Second Hatfield Memorial Lecture was delivered by Dr. C. Sykes, F.R.S., Director of Research of the Brown-Firth Research Laboratories, Sheffield, at The Institution of Civil Engineers, Great George Street, London, S.W.1, on Wednesday, 14th May, at 8.30 P.M. The subject of the lecture was "Steels for Use at Elevated Temperatures."

IRON AND STEEL ENGINEERS GROUP

The activities of the Iron and Steel Engineers Group continued through the year. In May, 1947, the Council appointed a number of further members to the Engineering Committee, resulting in its present composition as follows:

Chairman

W. F. CARTWRIGHT

Members

W. B. BAXTER	J. F. R. JONES
W. R. BROWN, D.S.O.	E. T. JUDGE
J. BUCHANAN	H. H. MARDON
H. S. CARNEGIE	G. A. PHIPPS
M. A. FIENNES	L. ROTHERA
D. C. HENDRY	I. S. SCOTT-MAXWELL

Ex Officio

Dr. C. H. DESCH, F.R.S. (President)
The Hon. R. G. LYTTELTON (Honorary Treasurer)

Meetings

The Group held three full-day meetings in 1947 at 4, Grosvenor Gardens, London, S.W.1. The following papers were presented and discussed:

Wednesday, 26th February, 1947

"The Blast-Furnace of Today," by W. R. Brown and I. S. Scott-Maxwell.

"Recent American Blast-Furnaces," by T. H. Stayman.

"Engineering Problems in the Preparation of Ores for Blast-Furnaces," by D. C. Hendry.

Wednesday, 11th June, 1947

"Water-Tube Boilers in Iron and Steelworks," by the Water-Tube Boiler Makers' Association.

"Steam Turbines in Iron and Steel Works," by I. V. Robinson.

"Gas Turbine Applications in Iron and Steel Works," by Dr. A. T. Bowden.

Wednesday, 26th November, 1947

"Mechanical and Electrical Features of Primary Hot-Rolling-Mill Auxiliaries," by W. W. Franklin and P. F. Grove.

"Modern Small Rolling Mills," by G. A. Phipps.

During the session 1947–48 Joint Evening Meetings were held by the Group with the Affiliated Local Societies at Scunthorpe, Wolverhampton, Sheffield, Swansea, Leeds, and Middlesbrough. Details of these meetings are included in the Programmes of the Affiliated Local Societies on pp. 424–426.

On 30th January, 1948, the Group held a Joint Evening Meeting with the West of Scotland Iron and Steel Institute in Glasgow to discuss "Gaseous and Liquid Fuels in Iron and Steel Works," by J. B. R. Brooke and J. S. Bryan.

The Group will hold three full-day meetings in London in 1948 and meetings in the provinces in the season 1948–49. The meetings in London will discuss the following subjects:

Wednesday, 18th February, 1948

"Gaseous and Liquid Fuels in Iron and Steel Works," by J. B. R. Brooke and J. S. Bryan.

"Soaking Pits," by the Society of Furnace Builders.

June, 1948 (*to be determined*).

"Electronic and Servo Electronic Controls and their Application to the Iron and Steel Industry," by W. G. Thompson.

"Electric Control Gear for Steel Mill Auxiliaries," by R. A. West.

"The Maintenance of Electrical Machinery in Iron and Steel Works," by G. S. Martin and M. Y. Harvey.

Wednesday, 24th November, 1948

"Conveyor Belts, Bunkers, and Shutes for Iron and Steel Works."

"Ore Discharging."

"Specialized Rolling Stock for Iron and Steel Works."

The papers and discussion at all the full-day meetings of the Group are published in the Iron and Steel Works Engineering Section of the *Journal*.

PUBLICATIONS

The *Journal* completed its first year of publication as a monthly in its new format, the twelve parts being divided into three volumes, Nos. 155 to 157.

Arrangements were made for binding cases and indexes to be issued together in the Spring of 1948.

Special Reports—The following two Special Reports were issued in respect of 1947, though publication of the second was deferred till early 1948:

Special Report No. 38—"Symposium on Powder Metallurgy."

Special Report No. 39—"Reports of the Affiliated Local Societies."

Translation Service—Translations of thirty-four foreign technical papers (Nos. 295 to 328) were included in the Institute's Translation Series; they are obtainable by Members at 10*s.* each (5*s.* for each additional copy of the same translation). The Council wish to record their thanks to those Companies, Research Associations, and other bodies which made translations available for inclusion in the Translation Series.

A number of translations which were not suitable for

inclusion in the Series were also made for Members at their own expense.

LIBRARY AND INFORMATION SERVICE

Joint Library

The usefulness of the Library was increased by the acquisition of important new works on metallurgy and by subscription for and exchange of the scientific and technical periodicals of many countries. The number of loans made reached 8675, as compared with the previous record of 7514 in 1946.

The Council's thanks are expressed to those Members and other authors who presented copies of books and papers; such contributions are greatly appreciated, and are of real value in maintaining the usefulness and completeness of the Library.

Information Service

Substantial progress was made during the year in the work of classifying the world's technical literature on metallurgy and allied subjects, and as a result the answering of technical queries was expedited. As previously reported, the Universal Decimal Classification has been adopted as a means of indexing, and a panel of the British Standards Institution, under the chairmanship of the Information Officer, has nearly completed a draft English edition of the Metallurgical Section.

The Council wish to draw the attention of Members to the services offered.

Three additions to the Institute's Bibliographical Series were published during the year:

No. 5A—"The Manufacture, properties, and testing of steel castings (not including moulding sands)." (Covering the period from 1936 to 1947.) (Supplement to No. 5.)

No. 13—"Wire (manufacture, treatment, and properties), including references to the cold-drawing of bars."

No. 14—"Steel Converter Practice (including multiplex processes)." (Covering the period from 1925 to 1946.)

In addition, a considerable number of shorter bibliographies were prepared at the request of Members at home and overseas.

Close co-operation was maintained with the British Iron and Steel Research Association and with industrial firms.

JOINT COMMITTEE ON METALLURGICAL EDUCATION

The work of the Joint Committee on Metallurgical Education (on which the Institute is represented, and for the secretarial arrangements of which it is responsible) and of the Institute's Education Officer continued on the lines previously reported.

Professor Leslie Aitchison succeeded Dr. C. H. Desch, F.R.S., as Chairman of the Committee, which was strengthened by co-opting representatives of industrial companies.

Subscriptions, to be renewed for a period of four years, were received on behalf of the various industries represented on the Committee, as a result of which a long-range policy, designed to improve the standard of metallurgical education of all kinds, could be begun.

NATIONAL CERTIFICATES IN METALLURGY

Satisfactory progress was made in the development of National Certificates in Metallurgy, schemes for Senior or Advanced Courses submitted by four examining bodies and sixteen technical colleges being approved for the year 1946–47. Eleven of these held examinations. Numerous additional schemes have been submitted for the year 1947–48.

The Institution of Metallurgists accepted an invitation to be represented on the Joint Committee, which also includes representatives of the Institute, the Institution of Mining and Metallurgy and the Institute of Metals, in addition to the Ministry of Education.

RELATIONS WITH OTHER SOCIETIES AND TECHNICAL INSTITUTIONS

The Institute has continued to maintain friendly relations with scientific societies and technical institutions at home and abroad.

Metallurgical Societies Overseas

Arrangements are now in force whereby members or the staffs of companies which are members of the undermentioned societies overseas may pay a membership subscription to the Institute of £2 12*s.* 6*d.* instead of £3 3*s.* 0*d.* (Entrance fee, £2 2*s.* 0*d.*); Associates up to the age of 28, £1 1*s.* 0*d.* instead of £1 5*s.* 0*d.* (no entrance fee):

American Institute of Mining and Metallurgical Engineers. (*The Associate age limit is* 33)

American Iron and Steel Institute

American Society for Metals

Association of Czechoslovak Mining and Metallurgical Engineers (Czechoslovakia)

Association Luxembourgeoise des Ingénieurs et Industriels (Luxembourg)

Canadian Institute of Mining and Metallurgy

Indian Institute of Metals

Instituto del Hierro y del Acero (Spain)

Jernkontoret (Sweden)

Koninklyk Instituut van Ingenieurs (Holland)

Norsk Metallurgisk Selskap (Norway)

Société Française de Métallurgie (France)

Société Royale Belge des Ingénieurs et des Industriels (Belgium)

Verein Schweizerischer Maschinen-Industrieller (Switzerland)

Representation at Anniversaries of Kindred Societies

The Institute was represented at the following anniversary celebrations of kindred societies by the persons named:

American Institute of Mining and Metallurgical Engineers: Seventy-fifth anniversary of foundation, 17th–19th March, 1947: Dr. C. H. Desch, F.R.S.

Institution of Mechanical Engineers: Centenary of foundation, 8th–13th June, 1947: Dr. C. H. Desch, F.R.S.

Association Luxembourgeoise des Ingénieurs et Industriels: Fiftieth anniversary of foundation, 14th and 15th June, 1947: Dr. C. H. Desch, F.R.S., and Mr. K. Headlam-Morley.

CHEMICAL SOCIETY : Centenary of foundation in 1841, celebrated on 15th–17th July, 1947 : Professor Thomas Turner.

ASSOCIATION DES INGÉNIEURS SORTIS DE L'ECOLE DE LIÈGE : Centenary of foundation, 1st–15th September, 1947 : The Hon. R. G. Lyttelton and Monsieur Léon Greiner.

JERNKONTORET : Bicentenary of foundation, 5th and 6th September, 1947 : Dr. C. H. Desch, F.R.S., Mr. Arthur Dorman, Sir Charles Goodeve, F.R.S., and Mr. K. Headlam-Morley.

INDIAN INSTITUTE OF METALS : Inaugural ceremony, 29th December, 1947 : Dr. D. P. Antia.

Co-operation with the Institute of Metals and the Institution of Metallurgists

The Council are pleased to be able to report that very friendly relations continue to be maintained with the Institute of Metals and with the Institution of Metallurgists, among both Members and staffs. A substantial proportion of the Institute's Members are also Members of one or both of the other societies, and a number of activities have been carried on jointly.

As previously announced, the arrangement by which the Secretary served also as Secretary of the Institute of Metals was terminated by mutual agreement on 30th June, 1947 ; from that date the two Institutes have employed separate staffs.

It has also been agreed that the Secretary shall cease to serve as Secretary of the Institution of Metallurgists—and that the staffs shall be separated—at a mutually convenient date depending on the appointment by the Institution of a Registrar-Secretary.

With the helpful collaboration of the Institute of Metals, accommodation continues to be provided for the Institution of Metallurgists in the Institute's building.

Affiliation with Local Societies

The Ebbw Vale Metallurgical Society became affiliated to the Institute as from 1st January, 1948, thus bringing the number of Affiliated Local Societies up to eight :

Cleveland Institution of Engineers
Ebbw Vale Metallurgical Society
Leeds Metallurgical Society
Lincolnshire Iron and Steel Institute
Newport and District Metallurgical Society
Sheffield Society of Engineers and Metallurgists
Staffordshire Iron and Steel Institute
Swansea and District Metallurgical Society

Under the schemes of affiliation the societies retain their complete independence, but agree to invite Institute Members to attend meetings organized by them in their districts, while the Institute pays to them a capitation grant of 5*s*. per Joint Member ; both parties undertake to assist and collaborate with the other.

Other Local Societies

Arrangements for collaboration were continued on previous lines with the Manchester Metallurgical Society, Sheffield Metallurgical Association, and the West of Scotland Iron and Steel Institute.

MEETINGS WITH OTHER SOCIETIES

Joint Meetings

A Joint Conference on Desulphurization and Dephosphorization, with Particular Reference to Cupola Iron, organized by the Institute of British Foundrymen in collaboration with The Iron and Steel Institute, was held at 4, Grosvenor Gardens, London, S.W.1, on 19th March, 1947, under the Chairmanship of Mr. D. H. Wood, President of the Institute of British Foundrymen ; the sessions started at 10.30 A.M. and 2.15 P.M., and a buffet lunch was served in the Library.

The subject-matter for discussion was the First and Second Reports of the Basic Cupola Committee and a paper on desulphurization, submitted by the Institute of British Foundrymen. They and the full discussion were published by that Society ; summaries appeared in the *Journal of The Iron and Steel Institute*.

Side-Blown Converter Refractories and Practice—By arrangement between the British Iron and Steel Research Association and the Institute, a Meeting, to which Members of the Institute of British Foundrymen were invited, was held on the Institute's premises on 20th March, 1947. Mr. F. Cousans deputized for Professor J. H. Andrew as Chairman. At the morning session (10.30 A.M.) "The First Report of the Converter Refractories Sub-Committee" was discussed, and "The First Report of the Side-Blown Converter Practice Sub-Committee" at the afternoon session (2.15 P.M.). A buffet lunch was available.

A Symposium on Internal Stresses in Metals and Alloys, organized by the Institute of Metals in association with the Faraday Society, the Institute of Physics, The Institution of Mechanical Engineers, the Physical Society, the Royal Aeronautical Society, and The Iron and Steel Institute, was held at the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, on 15th and 16th October, 1947.

On the first day two sessions (at 10.0 A.M. and 2.0 P.M.) on "Measurement of Internal Stresses" and on "Origin, Control and Removal of Internal Stresses" were held under the chairmanship of Dr. C. Sykes, F.R.S., and Professor Leslie Aitchison ; the third session, in two parts (at 10.0 A.M. and 2.30 P.M.), on "Effects Associated with Internal Stresses," presided over by Dr. Maurice Cook and Dr. H. J. Gough, F.R.S., was held on the second day. The 36 papers and discussion are being published in No. 5 of the *Monograph and Report Series of the Institute of Metals*.

Affiliated Local Society Meetings

The following Meetings of Affiliated Local Societies, which Members of The Iron and Steel Institute resident in the districts were entitled to attend, were arranged for the 1947–48 Session :

CLEVELAND INSTITUTION OF ENGINEERS : *President*, Mr. C. Moody. All Meetings in Middlesbrough.

3rd November, 1947 : "Development and Utilization of Stainless Steels," by Mr. W. W. Stevenson.

1st December, 1947 : "Combination Rolling Mills," by Mr. W. Udall.

5th January, 1948 : "Desiliconization," by Mr. E. F. Brown.

2nd February, 1948 : "Some Aspects of Modern Blast-Furnace Operation," by Mr. R. P. Towndrow.

1st March, 1948 : "Metallurgical Load as a Factor in Basic Open-Hearth Operation," by Mr. A. J. Kesterton.

8th March, 1948 : Film Display : "Four-High Plate Mills of the Lukens Steel Company, Coatsville, Pa., U.S.A.," presented by Mr. J. Malborn.

15*th March*, 1948: "Further Developments in Fluid Couplings," by Mr. A. Vickers.
5*th April*, 1948: Discussion on "Oil-Firing of Open-Hearth Furnaces," to be opened by Mr. G. B. Thomas and F. Kennedy.
12*th April*, 1948: "The Blast-Furnace of Today. A Review of Current Furnace Engineering," by Mr. W. R. Brown. (Joint Meeting with the Engineers Group of The Iron and Steel Institute.)

EBBW VALE METALLURGICAL SOCIETY (as from 1st January, 1948): *Chairman*, Mr. E. Hemingway-Jones. All Meetings in Ebbw Vale.

10*th February*, 1948: "Stainless Steel," by Mr. C. R. Pipe.
9*th March*, 1948: "Coal and the Future," by Dr. A. Parker.

LEEDS METALLURGICAL SOCIETY: *President*, Mr. A. Preece. All Meetings in Leeds.

2*nd October*, 1947: "Industrial Copper Alloys," by Mr. Edwin Davis.
6*th November*, 1947: "Magnesium Alloys," by Mr. R. G. Wilkinson.
3*rd December*, 1947: "Aluminium Alloys," by Mr. H. G. Warrington.
8*th January*, 1948: Symposium on Casting. "History of Steel Founding," by Mr. S. L. Finch; "The Mechanism of Freezing and Solidification," by Mr. G. W. Green; "Die Casting of Aluminium Bronzes," by Mr. C. R. Norwood; "Cast Iron and the Diesel Engine," by Mr. W. West.
5*th February*, 1948: "The Investigation of Failures," by Mr. C. P. Miller.
4*th March*, 1948: "Gas Turbine Applications in Iron and Steel Works," by Dr. A. T. Bowden.
1*st April*, 1948: "Controlled Atmospheres," by Mr. Ivor Jenkins.
6*th May*, 1948: Annual General Meeting and papers by Student Members: Mr. F. Lindars on "Electronics"; Mr. R. D. Carter on "Is our Iron and Steel Industry Efficient?"

LINCOLNSHIRE IRON AND STEEL INSTITUTE: *President*, Wing-Commander J. B. R. Brooke. All Meetings in Scunthorpe.

28*th October*, 1947: "The Steam and Gas Cycle," by Mr. F. J. Clark.
25*th November*, 1947: "District Heating: Making Use of Waste Heat from Steelworks," by Mr. D. V. H. Smith.
16*th December*, 1947: "Some Notes on Recent American Blast-Furnaces," by Mr. T. H. Stayman (presented in the author's absence by Mr. H. Welford). (Joint Meeting with the Engineers Group of The Iron and Steel Institute.)
27*th January*, 1948: "Oil-Firing of Open-Hearth Furnaces," by Mr. S. W. Evans.
17*th February*, 1948: Exhibition of Technical Films, by arrangement with The Iron and Steel Institute:
"Job 99—Pluto" (The Hamel pipeline under the sea).
"Steel" (A war-time record of the industry).
"The Making of Appleby Plates" (Practice at the Appleby-Frodingham Steel Co.).
"The Ten-Year Plan (Steel Houses)."
23*rd March*, 1948: "Desiliconization," by Mr. E. F. Brown.

NEWPORT AND DISTRICT METALLURGICAL SOCIETY: *President*, Mr. G. H. Latham. All Meetings in Newport (Mon.).

11*th October*, 1947: "Some Deformation Features of Steel," by Professor Hugh O'Neill.
8*th November*, 1947: "Electro-Tinning of Steel Strip," by Mr. C. Frenkel.
13*th December*, 1947: "Forged Steel Rolls," by Mr. A. H. Waine.
January, 1948: Visit to Newport Works of Messrs. Stewarts and Lloyds, Ltd.
26*th February*, 1948: Exhibition of Technical Films: "Pattern for Progress" (Messrs. Richard Thomas and Baldwins, Ltd.).
"Castings" and "Forgings" (High Duty Alloys, Ltd.).
17*th March*, 1948: "Developments in the Production and Uses of Bessemer Steel," by Dr. H. R. Dickie.

SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS: *Presidents*, Mr. Ambrose Firth (till 31st December, 1947), Mr. Basil W. Doncaster (from 1st January, 1948). All Meetings in Sheffield.

15*th December*, 1947: Symposium on the Use of Liquid Fuel in Open-Hearth Furnaces, introduced by Mr. F. A. Gray on "Instrumentation and Control of Oil-Fired Open-Hearth Furnaces," and Mr. H. C. White on "The Application of Oil Fuel to Open-Hearth Furnaces."
19*th January*, 1948: "Mechanical and Electrical Features of Primary Hot-Rolling-Mill Auxiliaries." Section I.—"Mechanical Features," by Mr. W. W. Franklin; Section II.—"Electrical Features," by Mr. P. F. Grove. (Joint Meeting with the Engineers Group of The Iron and Steel Institute.)
16*th February*, 1948: Exhibition of Technical Films, by arrangement with the Institute:
"Job 99—Pluto."
"From Mine to Metal—the Story of an Ore Sample" (Processes of extraction metallurgy, including froth flotation).
"Steel" (A war-time record of the industry).
15*th March*, 1948: "The Cold-Working of Metals," by Dr. C. H. Desch, F.R.S.
13*th April*, 1948: "Thin Films on Metals," by Dr. U. R. Evans.

STAFFORDSHIRE IRON AND STEEL INSTITUTE: *President*, Mr. W. M. Larke.

16*th October*, 1947: "Vitreous Enamelling of Ferrous Metals," by Mr. A. Biddulph (in Wolverhampton).
20*th November*, 1947: "Some Experiences with the Oil-Firing of Open-Hearth Furnaces," by Mr. G. R. Bashforth (in Dudley).
23*rd December*, 1947: Film Display: "The Making and Shaping of Steel" (in Wednesbury).
15*th January*, 1948: "Modern Small Rolling Mills," by Mr. G. A. Phipps (in Wolverhampton). (Joint Meeting with the Engineers Group of The Iron and Steel Institute.)
5*th February*, 1948: "Hardenability of Constructional Steels," by Dr. W. Steven (in Birmingham).
26*th February*, 1948: Exhibition of Technical Films (in Wolverhampton):
"The Production of High-Quality Steel" (Practice at the works of Messrs. Hadfields, Ltd.).
"They're Everywhere" (The making of nuts, bolts, screws, &c.).

25th March, 1948: "Controlled Charging of Open-Hearth Furnaces," by Mr. J. McCracken (in Dudley).

29th April, 1948: "Scrap from the Recoverer's Point of View," by Mr. F. L. Levy (in Wolverhampton).

SWANSEA AND DISTRICT METALLURGICAL SOCIETY: *President*, Mr. E. A. Davies. All Meetings in Swansea.

18th October, 1947: "Presidential Address," by Mr. E. A. Davies.

15th November, 1947: "Metal Surfaces," by Mr. M. R. Hopkins.

13th December, 1947: Discussion on "Oil-Firing of Metallurgical Furnaces," introduced by Mr. R. W. Evans, Mr. A. M. Gabe, and Mr. J. S. Lewis.

10th January, 1948: "The Galvanising of Sheets and Strip by the Hot-Dip Process," by Mr. H. Edwards.

21st February, 1948: "Engineering Aspects of a Modern Steel Plant," by Mr. W. F. Cartwright. (Joint Meeting with the Engineers Group of The Iron and Steel Institute.)

20th March, 1948: "Some Recent Trends and Future Possibilities in Ferrous Metallurgy," by Mr. R. A. Hacking, O.B.E.

Other Societies

The Iron and Steel Institute accepted invitations to collaborate in the following Joint Meetings:

4th November, 1947—SHEFFIELD METALLURGICAL ASSOCIATION, at Sheffield. *President*, Mr. T. F. Russell. "Hydrogen in Steel Manufacture," by Dr. C. Sykes, F.R.S., Mr. H. H. Burton and Mr. C. C. Gegg; "Hydrogen and Transformation Characteristics in Steel," by Professor J. H. Andrew, Dr. H. Lee, Mr. J. K. Lloyd and Mr. N. Stephenson.

26th November, 1947—MANCHESTER METALLURGICAL SOCIETY AND THE INSTITUTE OF METALS, at Manchester. Dr. L. C. Bannister in the Chair. "Some Metallurgical Problems in the Field of Atomic Energy," by Mr. E. W. Colbeck.

Additional Joint Meetings organized by the Iron and Steel Engineers Group are mentioned in the relevant section.

Members of the Institute were invited to be present at the following Meetings:

Conference on Pulverised Fuel, in Harrogate, on 3rd to 6th June, 1947, organized by the Institute of Fuel. Over fifty papers were presented.

The Tees-side Section of the Society of Instrument Technology Meeting, in Middlesbrough, on 15th October, 1947, under the chairmanship of Mr. W. J. Clark, Chairman of the Section. "Liquid Steel Temperature Measurement," by Mr. J. A. Hall.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Collaboration with the British Iron and Steel Research Association developed on the lines proposed in the previous Report. The Council wish to record their satisfaction at the friendly spirit which distinguished the relationship of the two staffs and deep appreciation of the unfailing interest and assistance in the Institute's work which was given by the Director and his staff.

PRESENTATIONS AND LOANS

The Council record their thanks to Members and others who have presented books, pictures, and historical records. In particular, acknowledgments are due to Jernkontoret and to a number of Swedish companies for the presentation of an important collection of books on the history of the Swedish steel industry.

HONOURS CONFERRED ON MEMBERS

The Council tender their warmest congratulations to the many Members of the Institute on whom honours have been conferred or who have received appointments in the period under review. Their names have been recorded in the monthly issues of the *Journal* during the year.

STAFF

The Council wish to record their appreciation of the services rendered by the staff.

APPOINTMENT OF REPRESENTATIVES

The following is a list of the Institute's representatives at 11th March, 1948:

BRITISH CAST IRON RESEARCH ASSOCIATION: Professor T. Turner.

BRITISH CORPORATION REGISTER OF SHIPPING AND AIRCRAFT, Technical Committee: Sir Andrew McCance, F.R.S.

BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION,
Sub-Committee J/E, Joint Committee, Steels for High Temperatures: Dr. J. W. Jenkin; *one appointment open.*
Sub-Committee F/J, Earthing to Water Mains: Dr. J. C. Hudson.

BRITISH IRON AND STEEL FEDERATION,
Statistical Committee: Mr. K. Headlam-Morley.
Films Panel: Mr. K. Headlam-Morley.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION, Council: Professor J. H. Andrew, Mr. N. F. Astbury, Mr. Arthur Dorman, Dr. E. Gregory, Sir William Griffiths, D.Sc., Professor R. Hay, Mr. T. M. Herbert, The Hon. R. G. Lyttelton, Dr. W. J. Rees.

BRITISH REFRACTORIES RESEARCH ASSOCIATION, Council: Mr. J. Sinclair Kerr.

BRITISH STANDARDS INSTITUTION,
General Council and Executive Committee: Mr. J. R. Beard (representing the Founder Institutions).
Chemical Engineering Industrial Standards Committee CHE/-: Mr. E. F. Law.
Engineering Divisional Council E/-: Mr. J. Sinclair Kerr, Mr. Vernon Harbord, Mr. K. Headlam-Morley.
Iron and Steel Industry Standards Committee ISE/-: Mr. F. H. Saniter.
Solid Fuel Industry Standards Committee SFE/-: Mr. A. F. Webber.
Technical Committee CEB/1, Cement: Mr. W. J. Brooke.
Sub-Committee CEB/6/1, Concrete Blocks: Mr. W. J. Brooke.
Technical Committee CHE/17, Symbols used in Diagrams of Chemical Engineering Plant: Mr. A. E. Chattin.
Sub-Committee CHE/18/2, Quality (Metallic Finishes): Mr. T. W. Whiting.
Sub-Committee CHE/18/4, Phosphate Coatings: Dr. J. C. Hudson.

Technical Committee ELE/28, Fans: Mr. A. F. Webber, Dr. A. M. Burdon.
Technical Committee HIB/15, Pressed Steel Galvanized Rainwater Goods: Dr. A. M. Burdon.
Technical Committee ISE/1, Co-ordination of Iron and Steel Specifications: Mr. S. Barraclough.
Technical Committee ISE/6, Steel Castings: Dr. R. H. Greaves, M.B.E.
Technical Committee ISE/8, Creep Properties: Mr. L. Rotherham.
Technical Committee ISE/11, Galvanized Corrugated Steel Sheets: Dr. J. C. Hudson.
Technical Committee ISE/15, Iron and Steel for Shipbuilding: Sir Edward J. George.
Technical Committee ISE/17, Cast Iron Columns for Street Lighting: Mr. J. G. Pearce.
Technical Committee ISE/28, Protective Coatings for Iron and Steel: Dr. J. C. Hudson.
Technical Committee ISE/35, Cast Iron: Mr. J. G. Pearce.
Technical Committee ISE/32, Iron and Steel Terms and Definitions: Mr. A. E. Chattin.
Technical Committee MEE/23, Indentation Hardness Testing: Mr. J. Woolman.
Technical Committee MEE/25, Testing of Metal Sheets and Strip: Dr. A. M. Burdon.
Technical Committee MEE/32, Engineering Symbols and Abbreviations: Dr. A. M. Burdon.
Technical Committee PSM/2, Welders' Goggles: Dr. C. H. Desch, F.R.S.
Technical Committee SFE/1, Nomenclature and Definitions for Solid Fuel Burning Appliances: Mr. A. F. Webber.
Technical Committee SFE/2, Underfeed Stokers: Mr. A. F. Webber.
Technical Committee SFE/9, Temperature Measurement, Gas Flow, and Pressure Measurement: Mr. Neil H. Turner.
Sub-Committee SFE/9/1, Temperature Measurement: Mr. Neil H. Turner.
Sub-Committee SFE/9/2, Fluid Meters and Flow Measurement: Mr. Neil H. Turner.
Technical Committee SFE/17, Sampling and Analysis of Flue Gases: Mr. F. A. Gray.
Units and Technical Data Co-ordinating Committee M/1: Sir Wm. Larke, K.B.E.
Letter Symbols Committee M/4: Dr. A. M. Burdon.

CITY AND GUILDS OF LONDON INSTITUTE, Advisory Committee on Metallurgy: Dr. J. W. Jenkin.

CLEVELAND INSTITUTION OF ENGINEERS, Council: Mr. Arthur Dorman.

CONSTANTINE COLLEGE, Advisory Foundry Committee: Mr. W. W. Stevenson.

EMPIRE COUNCIL OF MINING AND METALLURGICAL INSTITUTIONS: Mr. K. Headlam-Morley, Mr. J. Sinclair Kerr.

ENGINEERING PUBLIC RELATIONS COMMITTEE.
Main Committee: *appointment open.*
Executive Committee: Mr. K. Headlam-Morley.

HATFIELD MEMORIAL LECTURE COMMITTEE: Mr. K. Headlam-Morley, Dr. C. Sykes, F.R.S.

HONG-KONG UNIVERSITY, Home Committee: *appointment open.*

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, Board of Governors: Dr. C. H. Desch, F.R.S.

IMPERIAL INSTITUTE, Mineral Resources Department, Iron and Ferro-Alloy Metals Committee: Mr. K. Headlam-Morley.

INSTITUTE OF FUEL, Council: Professor R. J. Sarjant.

INSTITUTE OF METALS, Metal Physics Committee: Mr. D. A. Oliver; *one appointment open.*

INSTITUTE OF PHYSICS, Industrial Radiology Group, Sub-Committee on Terminology relating to Casting Defects revealed by X-Rays: Dr. R. Jackson.

INSTITUTION OF CIVIL ENGINEERS, Committee on Soil Corrosion of Metals and Cement Products, Sub-Committee on Soil Corrosion of Metals: Dr. J. C. Hudson.

INSTITUTION OF MECHANICAL ENGINEERS, Research Committee on High-Duty Cast Irons for General Engineering Purposes: Dr. J. E. Hurst.

INSTITUTION OF METALLURGISTS, Council: Mr. H. H. Burton, Mr. J. Sinclair Kerr.

JOINT COMMITTEE ON MATERIALS AND THEIR TESTING: Mr. K. Headlam-Morley.

JOINT COMMITTEE ON METALLURGICAL EDUCATION: Dr. C. H. Desch, F.R.S., Mr. R. A. Hacking, The Hon. R. G. Lyttelton.

JOINT COMMITTEE ON NATIONAL CERTIFICATES IN METALLURGY: Mr. R. A. Hacking, Dr. J. W. Jenkin.

KING'S COLLEGE, NEWCASTLE-UPON-TYNE (University of Durham), Metallurgy Advisory Committee: Mr. J. H. Patchett.

LEEDS METALLURGICAL SOCIETY, Council: Mr. A. Preece.

LINCOLNSHIRE IRON AND STEEL INSTITUTE, Council: Mr. W. B. Baxter.

LIVERPOOL UNIVERSITY, Court: Sir W. Peter Rylands, Bt.

LLOYD'S REGISTER OF SHIPPING, Technical Committee: Mr. H. H. Burton.

MOND NICKEL FELLOWSHIPS COMMITTEE: Dr. C. H. Desch, F.R.S.

NATIONAL COLLEGE FOR THE FOUNDRY INDUSTRY, Board of Governors: Mr. H. Cookson.

NATIONAL PHYSICAL LABORATORY, General Board: Professor J. H. Andrew, Mr. H. H. Burton.

NEWPORT AND DISTRICT METALLURGICAL SOCIETY, Council: Mr. G. H. Latham.

PARLIAMENTARY AND SCIENTIFIC COMMITTEE: Mr. K. Headlam-Morley.

RAMSAY MEMORIAL LABORATORY, Advisory Committee: *appointment open.*

ROYAL SCHOOL OF MINES, Advisory Board: Mr. Vernon Harbord.

ROYAL SOCIETY:
General Board for Administering Government Grants for Scientific Investigations: The President.
National Committee on Crystallography: Dr. C. Sykes, F.R.S.

SCHOOL OF METALLIFEROUS MINING (CORNWALL), Board of Governors: *appointment open.*

SCIENCE MUSEUM, Advisory Council: *appointment open.*

SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS, Council: Professor J. H. Andrew.

SHEFFIELD UNIVERSITY, Court of Governors: Sir Arthur B. Winder.

STAFFORDSHIRE IRON AND STEEL INSTITUTE, Council: Dr. J. E. Hurst.

SWANSEA AND DISTRICT METALLURGICAL SOCIETY, Council: Captain H. Leighton Davies, C.B.E.

WORSHIPFUL COMPANY OF BLACKSMITHS, Court of Assistants: Dr. C. H. Desch, F.R.S., the Hon. R. G. Lyttelton.

FINANCE

(The Accounts for 1947 are appended.)

General Fund—Balance Sheet

The Balance Sheet at 31st December, 1947, is presented in the usual form. A transfer of £840 was made from the Suspense Account for Repairs and Decorations to the Income and Expenditure Account to meet expenditure for which this reserve was established; the reserve now stands at £1160. The Entrance Fees Reserve Account and the Life Compositions Fund were increased by £765 and £320 respectively. The sum standing to the credit of the General Reserve, £3250, was transferred to the Accumulation Account and the excess of expenditure over income for the year, £6682, deducted from the latter. As usual, no value has been placed on subscriptions in arrears, the stock of *Journals* and office furniture and the Library.

The cost price of investments, the figure at which they are included in the Balance Sheet, was £34,322, a decrease of £4267 from the amount shown in the Balance Sheet for the previous year. The market value of the investments was £38,276. Sums of £28 and £790 were held as Cash at Bank on account of the legacy by Sir Robert Hadfield, Bt., F.R.S., and the Life Compositions Fund respectively, pending investment.

General Fund—Income and Expenditure Account

The Income and Expenditure Account is submitted in a simplified form, which is designed to show more clearly the cost of various activities on which the Institute is engaged. The comparable figures for the previous year are also given. Salaries of £20,361 net reflect the cost of the first full year of operating the post-war programme of development, and expenditure on staff superannuation at £2447 reflects the cost to the Institute of the first year's membership of the Metallurgical Societies Joint Pension Scheme. Expenditure, after deducting in each case the appropriate receipts, was £1662 on rent, lighting, heating and cleaning, £327 on Library books and binding, £1490 on publishing, and £2004 on meetings and travelling. Repairs and decorations cost £1419 of which £840 has been charged to the appropriate reserve.

The other main items of expenditure were honorarium and expenses of Historical Investigator £585, printing, stationery, postage, and other office expenses £3365, presentations and grants £467, and educational activities £400.

Income from Members' Subscriptions amounted to £10,879 and from Companies' Special Subscriptions £3884. The Council express their thanks to the subscribers. The Translation Service showed a surplus of £176. Interest on investments yielded £1425 and sundry receipts £96. The Grant from B.I.S.R.A. was £11,681, excluding payment of the cost of publishing on behalf of the Research Association, £4748. The final deficit for the year was £6682.

Andrew Carnegie Research Fund

The Balance Sheet and Income and Expenditure Account have been prepared in the usual form. After payment of grants, £300, expenditure on account of Salaries, Audit Fee and Medal, £165, and an addition of £500 to the General Reserve, the balance of £417, being excess of income over expenditure for the year, has been transferred to the Balance Sheet. The General Reserve stood at £2500 and accumulated surplus of income over expenditure at £6785. Investments at cost amounted to £29,965 as against £32,188 in the previous Balance Sheet, and their market value at 31st December, 1947, was £36,895. Loans to the General Fund of the Institute amounted to £4920; these loans have since been repaid.

Williams Prize Fund

Awards amounted to £100, and the balance, being excess of income over expenditure for the year, was £24. Accumulated balances of income over expenditure, as shown in the Balance Sheet, amounted to £667, and the cost price of investments remained unchanged at £2670; their market value at 31st December, 1947, was £3742. The loan of £126 to the General Fund of the Institute has since been repaid.

Bessemer Medal Fund

The value of the Bessemer Medal Fund at 31st December, 1947, consisting of £400 in 4% L.M.S.R. Debenture Stock, was £416. The income and expenditure of the Fund have, as usual, been included in the Income and Expenditure Account of the Institute's General Fund.

Railway Stock

Resulting from the transfer of holdings of Railway Securities into British Transport 3% Guaranteed Stock 1978–1988 (issued at par and redeemable at par) on 1st January, 1948, it is estimated that the annual income of the General Fund and Life Compositions Fund will be reduced by about £41 and the annual income of the Andrew Carnegie Trust Fund and Bessemer Medal Fund by £34 and £2 a year respectively.

THE IRON AND STEEL INSTITUTE

BALANCE SHEET, 31ST DECEMBER, 1947

1946 £	£	LIABILITIES	£	£
12,705		Sundry Creditors (part estimate)		15,330
		Amounts Received in Advance :		
	235	Members' Subscriptions	316	
	257	Special Subscriptions	128	
	93	Sales of Publications	580	
585				1,024
		Joint Committee on Metallurgical Education		218
179		Carnegie Research Fund		151
		Loans :		
		Carnegie Research Fund	4,769	
		Williams Prize Fund	126	
				4,895
	268	Legacy by Sir Robert Hadfield, Bart., F.R.S.	268	
	20	Accumulated Interest on Investments (Gross)	28	
288				296
		Bank Overdrafts :		
	984	General Account	—	
	98	Secretary's Account		62
1,082				
		Suspense Accounts as at 1st January, 1947 :		
	600	Reserve for Ten-Year Index	600	
	125	Bessemer Gold Medal	125	
	£1,000	Library Account	500	
	500	*Less* Transfer to Accumulation Account	—	
	500			
	2,000	Repairs and Decorations £2,000		
3,225		*Less* Transfer to Repairs Account, &c. 840		
			1,160	
				2,385
4,470		Entrance Fees Reserve Fund	4,470	
		Add Further Transfer, 1947	765	
				5,235
3,919		Life Compositions Fund	3,919	
		Add Profit on Realisation of Investment	26	
		Compounded during 1947	294	
			320	
				4,239
	3,750	General Reserve	3,250	
	500	*Less* Transfer to Accumulation Account	3,250	
3,250				—
		Iron and Steel Institute :		
	23,882	Capital as per last Balance Sheet	23,882	
		Add Profit on Realisation of Investments	459	
			24,341	
	214	Accumulated Excess of Income over Expenditure	214	
		Add Transfer from General Account	3,250	
			3,464	
		Deduct Excess of Expenditure over Income for the year	6,682	
			3,218	
24,096				21,123
£53,799				£54,958

1946 £	£	ASSETS	£	£
2,778		Sundry Debtors (Subscriptions in arrears, not valued)		5,352
		Payments in Advance :		
	429	Staff Superannuation Fund	184	
	250	Institution of Metallurgists	250	
	335	Sundries	141	
1,014				525
		British Iron and Steel Research Association :		
	4,453	Balance of Grant	6,682	
	4,380	Payment for Publications	5,466	
8,833				12,148
		Current Accounts :		
	1,381	Institute of Metals	460	
	569	Institution of Metallurgists	52	
	79	Joint Research Committees	4	
2,029				516
415		Joint Committee on Metallurgical Education		—
—		Stock of Journals		Not valued
—		Office Furniture and Library		Not valued
49		Cash in Hand		13
60		Post Office Savings Bank Account		5
		Cash at Bank—General Account		1,259
		Legacy by Sir Robert Hadfield, Bart., F.R.S. :		
	268	Investment at cost per Schedule	268	
	20	Cash at Bank	28	
288				296
		(The Market Value of this Investment at 31st December, 1947, was £273)		
		General Fund :		
34,405		Investments at Cost per Schedule		30,605
		(The Market Value of these Investments at 31st December, 1947, was £34,136)		
		Life Compositions Fund :		
	3,916	Investments at Cost per Schedule	3,449	
	3	Cash at Bank	790	
3,919				4,239
		(The Market Value of these Investments at 31st December, 1947, was £3,867)		
£53,799				£54,958

We have examined the above Balance Sheet of the Institute and certify it to be correct.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET,
LONDON, E.C.2.
March 16th, 1948.

(*Signed*) W. B. KEEN & Co.,
Chartered Accountants.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1947

INCOME

1946				
£	£		£	£
	965	Entrance Fees	765	
	965	*Deduct* Transfer to Reserve	765	
10,181		Subscriptions from Members		10,879
	4,093	Special Subscriptions	3,884	
	1,253	*Deduct* Transfer to Subscription and Entrance Fee Account	821	
2,840				3,063
379		Translations: Sales *less* Expenses		176
1,524		Interest on Investments (Gross)		1,425
104		Sundry Receipts		96
8,703		Grants from British Iron and Steel Research Association (Excluding £4,748 for Publications)		11,681
3,753		Balance, being Excess of Expenditure over Income		6,682
£27,484				£34,002

EXPENDITURE

1946				
£	£		£	£
	15,895	Salaries	23,183	
		Deduct Contributions:		
	1,208	Institute of Metals	£897	
	750	Institution of Metallurgists	1,000	
	150	Carnegie Research Fund	150	
	200	Joint Committee on Metallurgical Education	200	
	450	National Certificates Committee	450	
	—	Mond Nickel Fellowships	125	
			2,822	
13,137				20,361
145		National Insurance		217
311		Staff Superannuation Fund		2,447
—		Historical Investigator: Honorarium and Expenses		585
	2,361	Rent, Heating, Lighting and Cleaning	2,462	
	750	*Deduct* Contribution from Institute of Metals	800	
1,611				1,662
	1,334	Repairs, Decorations, Furniture and Fittings	1,419	
	—	*Deduct* Transfer from Reserves	840	
1,334				579
	733	Library Books and Binding	827	
	500	*Deduct* Contribution from Institute of Metals	500	
233				327
4,996		Publishing, *Less* Receipts from Advertisements, Sales and British Iron and Steel Research Association		1,490
	1,355	Meetings and Travelling	2,066	
	—	*Deduct* Surplus on Swiss Meeting	62	
1,355				2,004
3,279		Printing, Stationery, Postage, Telephone, Insurance and other Office Expenses		3,365
		Presentations and Grants:		
	123	Affiliated Local Societies	176	
	333	Other Grants	152	
	—	Presentations	139	
456				467
		Education:		
		National Certificates Committee:		
	300	Contribution	£150	
	200	Prize Fund	100	
			250	
		Joint Committee on Metallurgical Education:		
	25	Contribution	£50	
	—	Industrial Grant	100	
			150	
525				400
—		Bessemer Medal		5
—		Interest on Loans		41
52		Auditor's Fees		52
50		Transfer to Reserve—Ten-Year Index	—	
£27,484				£34,002

ANDREW CARNEGIE RESEARCH FUND

ANDREW CARNEGIE RESEARCH FUND

BALANCE SHEET, 31st DECEMBER, 1947

LIABILITIES

1946					
£	£		£	£	
		Sundry Creditors :			
	40	Grants	190		
	10	Auditor's Fees	10		
50				200	
2,000		General Reserve	2,000		
		Add Further Transfer, 1947	500		
				2,500	
	21,241	Amount of Original Fund, $100,000	21,241		
	4,441	*Add* Amounts since capitalized per last Balance Sheet	4,441		
		Profit on Realization of Investments	155		
	25,682		25,837		
	£5,756	*Add* Surplus Income as at 1st January, 1947	£6,368		
	612	Excess of Income over Expenditure for year	417		
	6,368		6,785		
32050				32,622	
£34,100				£35,322	

ASSETS

1946				
£	£		£	£
32,188		Investments at Cost per Schedule		29,965
		(The Market Value of these Investments at 31st December, 1947, was £36,895)		
		Cash at Bank :		
	602	On Current Account	202	
	109	On Deposit Account	9	
	876	Post Office Savings Bank Account	23	
1,587				234
146		Income Tax Recoverable		203
—		Iron and Steel Institute : Loan Account	4,769	
179		Current Account	151	
				4,920
£34,100				£35,322

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER 1947

INCOME

1946			
£		£	
1,288	Interest on Investments (Gross)	1,321	
15	Interest on Deposits	21	
—	Iron and Steel Institute—Interest on Loan	40	
£1,303			£1,382

EXPENDITURE

1946			
£		£	
—	Grants	300	
150	Contribution to General Fund on account of Salaries	150	
31	Printing Reports	—	
10	Audit Fee	10	
—	Medal	5	
500	General Reserve—Amount set aside	500	
612	Balance being Excess of Income over Expenditure for the year	417	
£1,303			£1,382

WILLIAMS PRIZE FUND

BALANCE SHEET, 31st DECEMBER, 1947

LIABILITIES

1946				
£		£	£	
	Capital value representing market value of £3,000 3½% Conversion Loan at			
2,220	21st September, 1926, when the Fund was inaugurated		2,220	
	Income and Expenditure Account :			
643	Balance as at 1st January, 1947	643		
	Add Excess of Income over Expenditure for year	24		
			667	
£2,863			£2,887	

ASSETS

1946				
£	£		£	£
2,670		£3,452 15*s.* 7*d.* 3½% Conversion Loan (at Cost)		2,670
		(The Market Value of this Investment at 31st December, 1947, was £3,742)		
		Cash at Bank :		
	65	On Current Account	59	
	128	Post Office Savings Bank Account	5	
193				64
—		Income Tax Recoverable		27
—		Iron and Steel Institute Loan Account		126
£2,863				£2,887

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1947

INCOME

1946			
£		£	
121	Interest on 3½% Conversion Loan	121	
3	Interest on Deposit	2	
—	Iron and Steel Institute—Interest on Loan	1	
26	Excess of Expenditure over Income for year	—	
£150			£124

EXPENDITURE

1946			
£		£	
150	Awards	100	
—	Balance being Excess of Income over Expenditure for year	24	
£150			£124

THE IRON AND STEEL INSTITUTE

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1947, SHOWING NOMINAL VALUES, COST AND PRESENT MARKET VALUES

Nominal Value	Nature of Security	Market Value, 31st December, 1947	Cost Value
	GENERAL FUNDS OF THE INSTITUTE		
£ s. d.		£	£
2,197 7 0	3½% War Stock	2,262	2,161
1,324 7 4	3½% Conversion Loan	1,397	1,254
447 0 0	Southern Railway 4% Debenture Stock	550	449
1,872 0 0	London & N. Eastern Railway 4% 2nd Guaranteed Stock	1,816	2,150
2,241 0 0	Do. do. 4% 1st Guaranteed Stock	2,308	2,432
1,500 0 0	Buenos Ayres Great Southern Railway 4% Debenture Stock	1,365	1,595
2,954 1 0	4% Consolidated Stock	3,190	3,176
437 0 0	London & N. Eastern Railway 3% Debenture Stock	434	376
12,242 19 3	4% Funding Loan 1960/90	13,222	9,512
2,000 0 0	3% Defence Bonds (P.O. Register)	2,000	2,000
2,000 0 0	3% Savings Bonds, 1955/65	2,040	2,000
2,000 0 0	Do. 1960/70	2,030	2,000
1,500 0 0	Do. 1965/75	1,522	1,500
		£34,136	£30,605
	LIFE COMPOSITION FUND		
587 13 10	3½% Conversion Loan	620	513
1,330 0 0	London & N. Eastern Railway 3% Debenture Stock	1,317	1,255
594 0 0	London Passenger Transport Board, 4½% "A" Stock	763	638
205 15 6	3½% War Stock	212	212
681 13 0	4% Funding Loan	736	600
196 10 1	Do.	219	231
		£3,867	£3,449
	ANDREW CARNEGIE RESEARCH FUND		
	(Trustees: Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton, and N. H. Rollason)		
6,897 14 11	3½% War Stock	7,105	6,896
800 0 0	Do.	824	794
2,693 12 0	3½% Conversion Loan	2,842	2,007
1,750 0 0	North Eastern Electric Supply Co. 3½% Consolidated Debenture Stock	1,697	1,762
1,500 0 0	Great Western Railway 4% Debenture Stock	1,845	1,204
2,000 0 0	London, Midland & Scottish Railway 4% Debenture Stock	2,080	1,693
1,312 0 0	London & N. Eastern Railway 4% 1st Guaranteed Stock	1,351	881
5,000 0 0	Do. do. 4% Debenture Stock	5,700	3,540
6,000 0 0	Do. do. 3% Debenture Stock	5,970	3,545
1,000 0 0	3% Savings Bonds, 1955/65	1,020	1,000
2,250 0 0	Do. 1960/70	2,284	2,250
1,250 0 0	3% Defence Bonds	1,250	1,250
500 0 0	Do.	500	500
2,166 18 7	4% Funding Loan, 1960/90	2,427	2,643
		£36,895	£29,965
	WILLIAMS PRIZE FUND		
	(Trustees: Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton and N. H. Rollason)		
3,452 15 7	3½% Conversion Loan	£3,742	£2,670
	SIR ROBERT HADFIELD LEGACY		
267 11 2	3% Savings Bonds, 1955/65	£273	£268
	BESSEMER MEDAL FUND		
	(Trustees: Desmond Lysaght, The Hon. R. G. Lyttelton, and N. H. Rollason)		
400 0 0	London, Midland & Scottish Railway 4% Debenture Stock	£416	—

(*Signed*) R. G. LYTTELTON,
Hon. Treasurer

(*Signed*) K. HEADLAM-MORLEY,
Secretary

We have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. We have also verified the balances at the Bankers and the Securities for the Investments shown above.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET, E.C.2.
March 16th, 1948

(*Signed*) W. B. KEEN & CO.,
Chartered Accountants

IRON AND STEEL INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

The Carbides in Iron–Carbon–Silicon Alloys and Cast Irons

By D. Marles

SYNOPSIS

A metallographic study has been made of the carbides occurring in cast irons and iron–carbon–silicon alloys with silicon contents up to 7% and carbon contents of 1·7–3·6%. It has been found that with silicon contents in excess of about 2·5%, a carbide phase appears which does not respond to heat-tinting in the same way as normal cementite. With increase in silicon up to 7% this phase increases in amount, whilst the normal cementite phase decreases until at 7% the carbide phase consists entirely of the constituent not responsive to heat-tinting. It is suggested that this carbide phase is a silico-carbide and that it has a lower stability at elevated temperatures than normal cementite.

Introduction

In the past there has been considerable discussion in the literature regarding the phases which should be present in iron–carbon–silicon alloys cooled under equilibrium conditions. Without dealing with this in great detail, it can be said that the more recent work (Jass and Hanemann[1]) seems to indicate that the phases which have to be considered in solidification under equilibrium conditions are graphite, solid solutions of graphite in iron, and iron–silicon compounds. Cementite is frequently regarded as a metastable phase which does not occur under equilibrium conditions of solidification. However, in commercial cast irons and in iron–carbon–silicon alloys cooled under non-equilibrium conditions, a phase appears in the microstructure which is generally described as cementite and assumed to be iron carbide, Fe_3C. Various alloying elements are known to exert a profound influence upon the stability of this phase, that is, upon its tendency to decompose to give graphite. Silicon renders cementite less stable; considerable importance, both theoretically and commercially, attaches to this behaviour of silicon.

A study of the literature upon the carbide phases in iron–carbon–silicon alloys reveals that the subject has received scant attention. In a paper written in 1910, Stead[2] suggested the occurrence of an iron silico-carbide and produced evidence in support of this. Recent workers on this subject have, however, ignored Stead's work. Stead suggested that instead of a ternary iron–carbon–silicon eutectic, two independent carbides crystallize from the liquid, one a silico-carbide and the other an iron carbide, which could be differentiated metallographically by heat-tinting. The normal carbide (cementite) responded to heat-tinting in the well-known manner, taking on a marked coloration owing to the formation of an oxide film, whereas the silico-carbide did not respond to heat-tinting. He also suggested that the silico-carbide was less stable than the normal iron carbide. Stead's work was complicated by the fact that several of his alloys contained appreciable amounts of sulphur and phosphorus. It was not supported by micrographic evidence, and no attempt was made to indicate within what range of silicon contents the silico-carbide phase occurred.

The experiments described in the present paper were carried out in an attempt to find whether the silico-carbide reported by Stead occurs in iron–carbon–silicon alloys and cast irons of low phosphorus, low manganese, and low sulphur contents, and to determine the limits of silicon necessary for its formation.

Reference to the possibility of a silico-carbide occurring in iron–carbon–silicon alloys has been made by Gontermann[3] and Andrew,[4] but these investigators do not contribute anything beyond that already suggested by Stead. Honda and Murakami,[5] Hanson,[6] Sawamura,[7] and Kříž and Pobořil[8] have suggested or implied the existence of complex carbides of iron and silicon in the iron–carbon–silicon system. No attempt

Manuscript received 5th November, 1947.

Mr. Marles is a member of the staff of the Metallographic Department of the British Cast Iron Research Association, Birmingham.

had been made to isolate or identify them and the evidence for their existence depended solely upon the fact that the carbide phase in alloys with a high percentage of silicon showed only a faint coloration compared with that of cementite on etching in hot alkaline sodium picrate solution. Hurst and Riley[9] have also commented upon the occurrence of a carbide phase in iron–carbon–silicon alloys with 10–15% of silicon. This phase, they reported, was not blackened by etching with the sodium picrate reagent. These investigators also suggested that the carbon content of this phase might be lower than that of normal cementite.

CARBIDE-CONTAINING IRON–CARBON–SILICON ALLOYS

As has been mentioned previously, silicon reduces the stability of cementite, and in normal iron–carbon–silicon alloys and cast irons containing more than 1% of silicon it is only by fairly rapid cooling that the carbide phase can be retained. This graphitizing influence of silicon may be offset by the inclusion of carbide-stabilizing elements, such as chromium and sulphur. The influence of these elements is not, however, fully understood, and so their use in producing carbides for study is not satisfactory. The stability of the carbides may, however, be increased by superheating the melt before casting. For instance, if a melt containing 2·0–2·5% of carbon and 5–6% of silicon is superheated to a temperature above 1650° C. it is possible, even when the metal is cast in a sand mould, to retain the carbide phase. The author's first observations were carried out upon commercially made cast irons of this type. These cast irons contained approximately 1·9% of carbon and 5% of silicon and were produced commercially in a direct-arc electric furnace, the metal being superheated to a temperature above 1600° C. Metallographic examination was made of those samples containing carbide and it was found that even under ordinary vertical illumination the carbide areas were duplex and consisted of two phases of slightly differing reflectivity. Under polarized light between crossed nicols the distinction between the two phases was again discernible, one phase (probably normal cementite) being anisotropic, whilst the other showed no recognizable anisotropy. The appearance, under vertical illumination, of the carbide phase after normal etching in a 4% solution of picric acid in alcohol, is shown in Fig. 1. Upon heat-tinting in air at about 300° C., a clear differentiation, as suggested by Stead, was obtained as shown in Fig. 2. The carbide areas are now seen to consist of two phases, one appearing dark, which has responded in the normal way to heat-tinting, and one appearing light, which has remained unaffected by heat-tinting. The manganese content of this sample was 0·5%, the sulphur content 0·06%, and the phosphorus content 0·08%. Clearly this evidence confirms the suggestion by Stead that two carbide phases can occur in iron–carbon–silicon alloys.

MELT NO. 1

In order to investigate the influence of silicon upon the occurrence of the duplex carbide structure, synthetic iron–carbon–silicon alloys were prepared from Lowmoor iron, electrode carbon, and silicon metal. The total weight of the melt was approximately 7 lb. The charge was calculated to give an alloy containing 3% of carbon and 2% of silicon. After superheating the melt to a temperature of 1600° C., a small cylindrical ingot, 0·875 in. in dia. and 5 in. long, was cast in a graphite mould which had been previously heated to a temperature of 100° C. A further addition of silicon metal was made to the melt and another ingot cast, allowing adequate time for the solution of the metallic silicon and for the restoration of the superheat. This process was repeated until four such ingots had been cast of the compositions given in Table I.

It will be observed that there was a progressive drop in carbon content throughout this series, as would be expected from the influence of silicon on the solubility of carbon in the melt. Ingots 1, 2, and 3 were completely white, and ingot 4 was mottled. Figure 3 shows the microstructure of ingot 1 after normal etching in picric acid. The appearance of the same specimen after heat-tinting is shown in Fig. 4, in which it will be observed that the whole of the carbide phase has been heat-tinted. The white phase associated with carbide is ferrite. Ingot 2, with a silicon content of 3·94%, showed carbide areas having a duplex structure. The normal microstructure of this sample after etching in picric acid is shown in Fig. 5, and Fig. 6 shows the appearance of the same sample after heat-tinting. In the latter micrograph it can be seen that not all of the carbide has responded to heat-tinting; some has remained without any coloration.

Table I

COMPOSITIONS OF INGOTS FROM MELT NO. 1

Ingot No.	T.C., %	Si, %	Mn, %	S, %	P, %
1	3·06	2·21	0·56	0·019	0·030
2	2·54	3·94	...	...	...
3	2·17	5·28	...	...	...
4	1·70	6·69	...	...	...

It may be deduced that the carbide phase not responsive to heat-tinting begins to appear in iron–carbon–silicon alloys when the silicon content exceeds a value somewhere between 2·2% and 3·9%. Ingot 3, with 5·28% of silicon, showed still more of the phase not responsive to heat-tinting. The general structure of this sample as it appeared when etched in picric acid is shown in Fig. 7. After heat-tinting, the two carbide phases could be seen, but their manner of juxtaposition varied in different parts of the specimen. In some areas the two phases were relatively massive; a typical example of this arrangement is shown in Fig. 8. In other areas the carbide phase which responded to heat-tinting was distributed in the form of fine striæ running approximately parallel through masses of the phase which did not respond to heat-tinting (*see* Fig. 9). In ingot 4, only very small traces were found of the normal carbide responsive to heat-tinting. The general structure of the white

Fig. 1—Etched in 4% picric acid in alcohol. × 350

Fig. 2—Etched in 4% picric acid in alcohol and heat-tinted. × 350

Figs. 1 and 2—Commercially made cast iron containing 1·9% of carbon and 5% of silicon

Fig. 3—Etched in 4% picric acid in alcohol. × 350

Fig. 4—Etched in 4% picric acid in alcohol and heat-tinted. × 800

Figs. 3 and 4—Ingot 1 from melt No. 1

Fig. 5—Etched in 4% picric acid in alcohol. × 800

Fig. 6—Etched in 4% picric acid in alcohol and heat-tinted. × 800

Figs. 5 and 6—Ingot 2 from melt No. 1

Fig. 7—Etched in 4% picric acid in alcohol. × 800

Fig. 8—Etched in 4% picric acid in alcohol and heat-tinted. × 800

Figs. 7 and 8—Ingot 3 from melt No. 1

Fig. 9—Ingot 3 from melt No. 1. Etched in 4% picric acid in alcohol and heat-tinted. × 800

Fig. 10—Etched in 4% picric acid in alcohol. × 800

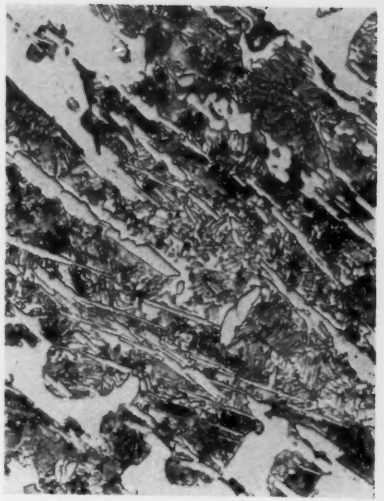


Fig. 11—Etched in 4% picric acid in alcohol and heat-tinted. × 800

Figs. 10 and 11—Ingot 4 from melt No. 1

Fig. 12—Etched in 4% picric acid in alcohol. × 1500

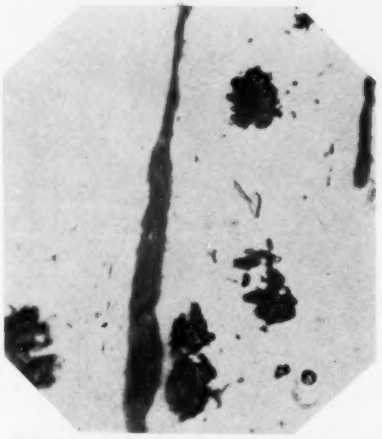


Fig. 13—Etched in 4% picric acid in alcohol and heat-tinted. × 1500

Fig. 14—Etched in 4% picric acid in alcohol and heat-tinted. × 1500

Figs. 12 to 14—Melt No. 3

iron in this ingot after etching with picric acid may be seen in Fig. 10, and the appearance of this white iron after heat-tinting in the usual manner may be seen in Fig. 11.

From these experiments it is clear that the carbide phase not responsive to heat-tinting increases in amount with increase in silicon until it has completely displaced the normal carbide, when the silicon content is slightly in excess of 6·7%. It is interesting to observe the sharp line of demarcation between the two types of carbide and also the mode of their relative distribution. This suggests that the influence of silicon is not a progressive influence due to a gradually increasing silicon content of the carbide as a whole, but that the silicon may be segregated in certain portions of the carbide, possibly with the formation of a silico-carbide. That a silico-carbide should be resistant to oxidation under the heat-tinting operation is not surprising, in view of the known effect of silicon in increasing resistance to oxidation.

Table II

COMPOSITIONS OF INGOTS FROM LOW-MANGANESE SERIES, MELT NO. 2

Ingot No.	T.C., %	Si, %	Mn, %	S, %	P, %
1	2·76	1·89	0·03	0·013	0·14
2	2·69	2·35	...	...	...
3	2·49	2·75	...	...	...
4	2·39	3·20	...	...	...
5	2·19	3·92	...	...	...
6	1·80	4·24	...	...	...
7	1·76	4·83	...	...	...
8	1·67	5·85	...	...	...

MELT NO. 2—LOW-MANGANESE SERIES

In ingots obtained from melt No. 1 there was an appreciable amount of manganese originating from the Lowmoor iron used in the charge. The influence of this manganese upon carbide formation needs to be taken into account. In addition, ingot 4 contained appreciable amounts of graphite. It was decided, therefore, to prepare another series with increasing silicon content, but from material of much lower manganese content, and to cast smaller ingots in the hope of reducing the amount of graphite in those with high silicon contents by more rapid cooling. For this purpose a base iron was prepared by melting together wrought iron and carbon. Seven pounds of this base iron were remelted in a small high-frequency induction furnace and eight small ingots of increasing silicon content were cast by making additions of silicon metal to the melt after each ingot had been poured. Ingots were cast in graphite moulds held at 100° C. and were in the form of bars 0·5 in. in dia. and 3 in. long. The analyses of these ingots are given in Table II. It will be noted that the carbon contents of these ingots again fall progressively throughout the series.

Metallographic examination of these ingots showed that the phase not responsive to heat-tinting was definitely present in ingots 3–8, the amount increasing as the silicon content increased. This phase was not present in ingot 1, but it is possible that some may have been present in ingot 2. However, its detection in small quantities is difficult and in this case its presence was not certain. Ingot 8 had a structure very similar to that of ingot 3 of melt No. 1 and contained a mixture of the two carbide phases, but in a more finely divided form, owing to the greater cooling rate.

In spite, therefore, of the difference in manganese content between melts Nos. 1 and 2, the carbides show approximately the same appearance with increasing silicon content. It may, therefore, be concluded that manganese has little or no effect and that the silicon content is the determining factor. Melt No. 2, however, indicates that the silicon content at which the carbide phase not responsive to heat-tinting begins to appear is between 2·2 and 2·75%.

MELT NO. 3—STABILITY OF THE TWO CARBIDE PHASES

Silicon is known to reduce the stability of iron carbide during annealing as well as during solidification. This appears to be a progressive influence with increase in silicon content, although with larger percentages of silicon (15%) Hurst and Riley[9] have commented on the unexpected stability of the carbide phase. If the phase which has been described in this paper and which is not responsive to heat-tinting is, in fact, a silico-carbide, it might be anticipated that it would have a lower stability than that of the normal carbide.

A melt was made up from wrought iron, silicon metal, and electrode carbon, and seven small ingots, 0·5 in. in dia., were cast in graphite moulds from the same bath of molten metal. One of these ingots was analysed, giving the following composition:

T.C., %	Si, %	Mn, %	S, %	P, %
2·35	5·12	0·02	0·013	0·106

After etching and heat-tinting, metallographic examination revealed that both carbide phases were present roughly in the amounts as illustrated in Figs. 8 and 9. It was decided that samples from these ingots should be annealed to study whether the two carbide phases decomposed to give graphite at differing rates. At first, the annealing experiments were carried out at 850° C., but as graphitization was complete in one hour it was decided to anneal at 700° C., so that the progress of graphitization with time could be studied in greater detail. With times of annealing of up to 1½ hr. at 700° C., no graphitization occurred. After 2½ hr. annealing, graphitization was appreciable, but areas of both types of carbide were visible after heat-tinting. This is illustrated in Fig. 12 where graphite, normal cementite responsive to heat-tinting, and the phase not responsive to heat-tinting can be seen in a matrix of silico-ferrite. After 3½ hr. annealing at 700° C. graphitization was more advanced, but in this case only normal cementite remained—all of the carbide phase not responsive to heat-tinting had decomposed. Some of the graphite resulting from this carbide decomposition was in the form of small nodules, as in Fig. 13, which is a micrograph taken from the sample annealed for 3½ hr. at 700° C. The normal cementite is seen, together with graphite nodules. In other areas of the specimen the

Fig. 12—Etched in 4% picric acid in alcohol. × 1500 Figs. 12 to 14—Melt No. 3

graphite was arranged in flake-like aggregates closely adjacent to the normal carbide phase (*see* Fig. 14).

It is considered that this experiment clearly reveals the phase not responsive to heat-tinting to be less stable at elevated temperatures than is the normal cementite. Thus the influence of silicon in promoting graphitization in iron–carbon–silicon alloys is explained for silicon contents in excess of about 2·5% to be due to its influence in increasing the amount of the second carbide phase. This explanation is not, however, very satisfactory, since, as has been mentioned previously, silicon exerts a progressive influence on carbide stability even when the silicon content is below this figure.

INFLUENCE OF CARBON CONTENT

In the original paper by Stead it was suggested that, as the total carbon content is increased with fixed silicon content, the silico-austenite decreases in amount and as a result the released silicon forms more silico-carbide (the phase not responsive to heat-tinting). To check this point two melts were made giving ingots of increasing carbon content for silicon contents of 2% and 2·9%. The phase not responsive to heat-tinting was not present with 2% of silicon, but was present in a small amount with 2·9%. Although the carbon contents studied at these silicon contents covered a wide range, giving hypo- and hyper-eutectic alloys, no influence of carbon content was thus observed upon the type and amounts of carbides formed. It was thus not possible to confirm the statement made by Stead.

SUMMARY AND CONCLUSIONS

It will be seen from the few experiments described in the foregoing that an interesting aspect of iron–carbon–silicon alloys has been largely overlooked since the original suggestion by Stead of the occurrence of a carbide phase containing silicon. Stead actually refers to the phase not responsive to heat-tinting as a silico-carbide. From the evidence presented in this paper it would seem reasonable to suppose that some combination of silicon and iron carbide can occur in iron–carbon–silicon alloys. If it were a simple case of the solution of silicon in iron carbide, one would expect the effect of silicon on the response of the carbide to heat-tinting to be progressive and, in any one area of carbide, to be uniform. In actual fact, the areas not responsive to heat-tinting are distributed in a regular pattern in a given carbide mass and there is a sharp line of demarcation between the two types of carbide. For this reason the author favours the view that some combination of silicon and iron carbide occurs, and prefers to use the term iron silico-carbide to define the phase not responsive to heat-tinting.

The following conclusions are drawn :

(1) In metastable iron–carbon–silicon alloys the carbide phase has a duplex structure for silicon contents between approximately 2·5% and 7%. It is realized that these limitations of silicon content may only apply to the conditions of casting and cooling described in this paper. With slower or faster cooling the limits may vary.

(2) Below about 2·5% of silicon, the carbide phase appears to be normal cementite responsive to heat-tinting.

(3) With silicon contents in excess of 2·5% a carbide phase appears which is not responsive to heat-tinting. The amount of this phase which may be an iron silico-carbide increases with increasing silicon content, until at approximately 7% of silicon all the carbide is in this form and no normal cementite occurs.

(4) The carbide phase introduced by silicon within the range given above appears to be less stable at elevated temperatures than the carbide phase responsive to heat-tinting.

(5) Variations in carbon content do not appear to influence the limits of silicon content within which the silico-carbide can occur, nor do they appear to affect the relative proportions of the two carbides.

Acknowledgments

The author wishes to express his thanks to the Director and Council of the British Cast Iron Research Association for permission to publish this paper, and also to Mr. H. Morrogh for his advice throughout the investigation and during the preparation of the paper.

References

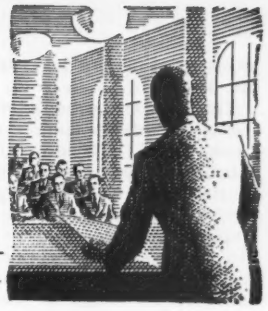
1. H. JASS and H. HANEMANN : *Giesserei*, 1938, vol. 25, pp. 293–299.
2. J. E. STEAD : British Association, 80th Report, Sheffield, 1910, Section *B*, Chemistry, pp. 549–561.
3. W. GONTERMANN : *Journal of The Iron and Steel Institute*, 1911, No. I, pp. 421–475.
4. J. H. ANDREW : *The Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1916, vol. 7, pp. 3–17.
5. K. HONDA and T. MURAKAMI : *Journal of The Iron and Steel Institute*, 1923, No. I, pp. 545–584.
6. D. HANSON : *Journal of The Iron and Steel Institute*, 1927, No. II, pp. 129–183.
7. H. SAWAMURA : *Memoirs of the College of Engineers, Kyoto Imperial University*, 1926, vol. 4, No. 4, pp. 159–260.
8. A. KŘÍŽ and F. POBOŘIL : *Journal of The Iron and Steel Institute*, 1930, No. II, pp. 191–293 ; 1932, No. II, pp. 323–349.
9. J. E. HURST and R. V. RILEY : *Journal of The Iron and Steel Institute*, 1944, No. I, pp. 213P–219P.

Temper-Brittleness and Related Phenomena

Report No. MG/AA/81/47 of the Hair-Line Crack Sub-Committee, Metallurgy (General) Division, of the British Iron and Steel Research Association, is a review of temper-brittleness and related phenomena in steel, by H. Evans.

In the first section of the report the author draws attention to researches dealing with the effect on properties other than the notched impact value, and as the conclusion is drawn that it is only this property which critically reveals the incidence of temper-brittleness, the main part of the report deals with the notched impact properties ; it is subdivided into sections on the effect of factors such as testing temperature, heat-treatment, steelmaking practice, and composition. In conclusion the present position is outlined, and suggestions are given for possible further work. Bibliographies to the report and to its appendix contain sixty-seven references to the literature.

DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Autumn Meeting, 1947

Joint Discussion on the Papers—

HYDROGEN AND TRANSFORMATION CHARACTERISTICS IN STEEL*

by J. H. Andrew, H. Lee, H. K. Lloyd, and N. Stephenson

and—

HYDROGEN IN STEEL MANUFACTURE†

by C. Sykes, F.R.S., H. H. Burton, and C. C. Gegg

Professor **J. H. Andrew** (University of Sheffield), in introducing the paper entitled "*Hydrogen and Transformation Characteristics in Steel*," said: This work was carried out at the instigation of B.I.S.R.A., and should have been included in the section devoted to B.I.S.R.A. papers. Through an oversight on my part that was not done, and I ask Sir Charles Goodeve to accept my apologies. My colleagues would like to thank B.I.S.R.A. for the financial aid given to them in the course of this work.

Mr. H. H. Burton (English Steel Corporation, Ltd.) presented the paper entitled "*Hydrogen in Steel Manufacture.*"

DISCUSSION

Mr. **A. J. K. Honeyman** (Messrs. Colvilles, Ltd., Glasgow): The authors of both these papers are to be congratulated on carrying out an immense amount of difficult and somewhat tedious experimental work, and on presenting the results of their researches in a very clear manner. Professor Andrew and his colleagues will, I am sure, be particularly glad that the work of Dr. Sykes and his colleagues has confirmed that where hydrogen is introduced deliberately in steel it has in almost every respect the same effect as when it is present in the normal course of manufacture. Makers of heavy steel alloy forgings will be particularly grateful to Dr. Sykes and his co-authors for their work. The work on wild ingots is a very good illustration of the saying that "Sweet are the uses of adversity."

Referring first to the paper by Dr. Sykes, Mr. Burton, and Mr. Gegg, the data recorded in Tables XI–XIII are particularly interesting, and confirm my own experience, expressed in the discussion on Professor Andrew's first paper on this subject five years ago, that isothermal transformation in the pearlitic region removes the danger of hair-line cracks. We applied this successfully to armour plate during the war, though at that time we thought that it was necessary to prolong the soaking in the isothermal region to remove the hydrogen.

I think that these papers may be said to have solved the practical problems in relation to hydrogen in steel—the prevention of hair-line cracks, the effect of hydrogen on the mechanical properties, and the necessity of removing the hydrogen, or, where that cannot be done, of preventing it as far as possible from getting into the steel.

It is impossible in the short time at my disposal to discuss the whole paper, and I can only select points of particular interest to myself. Dr. Sykes has correctly said that the bibliography is so extensive and the subject so complex that the interpretation of any particular set of experimental results depends very often on the particular theory of crack formation which the author favours. I must confess to being guilty of that, as no doubt many others are; I have a particular theory, to which I shall refer later.

The authors have given numerous examples to show that after isothermal transformation and softening, steels with high hydrogen contents may be reheated to as high a temperature as 1200° C. and air-cooled without the formation of hair-line cracks. On the other hand, Professor Andrew and his colleagues obtain hair-line cracks by long soaking in an atmosphere of hydrogen. I presume that Professor Andrew's steels were immunized prior to the hydrogen treatment; certainly one of the

* *Journal of The Iron and Steel Institute*, 1947, vol. 156, June, pp. 208–253.

† *Journal of The Iron and Steel Institute*, 1947, vol. 156, June, pp. 155–180.

steels described in his 1942 paper was so treated by Mr. Burton.

There are two essential differences between the treatments of Professor Andrew and his colleagues on the one hand and of Dr. Sykes and his colleagues on the other. First, in the one case the hydrogen is diffusing in, and in the other it is diffusing out. Secondly, Professor Andrew's soaking time was much longer than that employed by Dr. Sykes. On page 164 of his paper, Dr. Sykes—and in mentioning Dr. Sykes and Professor Andrew I must be understood to include their collaborators—suggests that his treatment prevents hair-line cracks because it enables the hydrogen to be accommodated in a manner which does not induce hair-line cracks. It is difficult to visualize hydrogen being accommodated in one manner while diffusing into the steel and in a different manner while diffusing out, and I should like Dr. Sykes to elucidate that further. I suggest that a more probable explanation would be that the soaking time may have a very pronounced influence on the transformation characteristics of the steel, which have a very pronounced influence on hair-line crack formation. It may well be also that it is not hot working which results in proneness to hair-line cracks, but the prolonged soaking at the high temperature which usually precedes hot working.

On page 178 Dr. Sykes states that there are many cases on record where cracking occurs long after the breakdown of the austenite has been completed. Will he state what evidence there is to refute the suggestion that the incubation period is due to the presence of minute quantities of retained austenite which transform immediately before cracking takes place ? For example, on page 166 it is suggested that the treatment given to sample *J*6 led to full softening, whereas *R*2 was still in the hardened condition. As stated by Dr. Sykes, it is apparent that *R*2 in the condition before water-quenching from 500° C. had some retained austenite. In view of the fact that *R*1 and *J*6 have much the same hardness, it is not unlikely that *J*6 also had some retained austenite before being air-cooled, although hair-line cracks were not present. Our experience of 3% nickel steel is that when fully transformed in the pearlitic region at about 600° C. the Brinell hardness obtained is approximately 190, whereas with *J*6 it was 203.

My own view is that hair-line cracks arise primarily from a transformation of minute quantities of residual austenite rich in hydrogen. Whether this results in hair-line cracking will depend upon the amount of hydrogen and the mechanical properties of the matrix in which the residual austenite transforms. When the hydrogen content is high, cracking may occur in a soft matrix, whereas a higher matrix hardness may not result in hair-line cracking provided that the hydrogen content is low. For example, the 3% nickel steel discussed by Dr. Sykes, pit-cooled, with low hydrogen, may under normal conditions not show hair-line cracks, but when the hydrogen content is high, as with the wild ingot, pit-cooling is not sufficient to prevent hair-line cracks. Heat-treatment giving a matrix hardness of 207, as in the case of *R*1, may cause hair-line cracks when the hydrogen content is high.

The only statement in Dr. Sykes' paper which shakes my belief in my theory is the statement on page 180 that high-chromium martensitic steels are not subject to hair-line cracks. I must confess that I have no experience of such steels, and I should be grateful if Dr. Sykes would give us some more information and tell us on what grounds that statement is based.

Unlike Dr. Sykes, Professor Andrew does not appear to attach much importance to the possible effects of segregation and retained austenite. On page 214 exceptions are quoted to the general rule that steels which undergo transformation at higher temperatures evolve more hydrogen during cooling, but I would submit that these steels are just those in which segregation, and therefore retained austenite, are most likely to be present.

With regard to the effect of alloying elements, and particularly carbon, on the retention of hydrogen, I suggest that a partial explanation, if not a complete one, might well be found on the basis of retained austenite. The amount of retained austenite is not necessarily related to the temperature at which the pearlitic transformation takes place. Professor Andrew's first paper on this subject, published five years ago, gave confirmation of my own views, and indeed my views were partly based thereon. For that reason I should very much like to ask him how he would now explain the white streaks which he so carefully described in that paper.

Dr. **C. Sykes**, F.R.S. (Brown-Firth Research Laboratories, Sheffield) : I have read the paper by Professor Andrew and his colleagues with very great interest.

In the present paper the authors introduce certain new ideas over and above the ones which were contained in their earlier papers. They now state that the rate of diffusion and the apparent solubility of hydrogen vary with the condition of the steel even in the α state. In other words, in any particular alloy steel, depending on the way in which it has been transformed, the rate of diffusion may vary and the apparent solubility can vary. Thus it is not excluded that two samples of the same steel having the same hardness in the α condition, but transformed in different ways, may have different diffusivities and solubilities.

We may review these statements from two points of view, one practical, the other theoretical. In the first place, of course, as steelmakers we want to know what is the condition into which we must put the steel in order to get the hydrogen out of it as quickly as possible —should it be fully softened or fully martensitic or in some intermediate condition ?—and I should like the authors to answer that specific question. From the point of view of speculation I find it rather difficult to understand how the rate of diffusion can vary appreciably with the condition of the material in the α state. We know, of course, that a cold-worked material precipitation-hardens much more rapidly than one which is not cold worked, and presumably the rate of diffusion is somewhat greater, but here, of course, the hardness is different in the two conditions. Normally, if diffusivity behaved similarly to thermal conductivity one would expect maximum diffusivity in the fully softened condition. Do the author's experiments lead to any simple generalization of this type ? I find it still more difficult to understand how the apparent solubility varies with the condition in the α state unless there is some form of chemical combination, and I should like the authors to elaborate that point.

They have introduced two further ideas which I think are very interesting. One is that the hydrogen may segregate at the boundaries of the mosaic, and the second is that the mosaic may form only at temperatures below, shall we say, 250° C. In that way they produce a hypothesis which might explain the incubation period and the fact that very often hair-line cracks form at room temperature.

I am under the impression that one of the main reasons for assuming that there is a mosaic structure of metals— there are various reasons, but this is one of the

strongest—is the fact that the X-ray reflection from a metal crystal is very much stronger than it would be if the crystal were perfect, and it is because it is not perfect that we get a very strong X-ray reflection. On the other hand, I am also under the impression that the X-ray reflection from a metal crystal does not undergo any anomalous change when we change the temperature of the crystal from room temperature to, say, 600° C. The intensity varies, but it varies by a temperature factor which is considered to be understood, and there is no discontinuity.

This suggests that the mosaic pattern exists to temperatures well above that of 250° C. postulated by the authors. However, this need not affect the validity of their hypothesis that hydrogen uses the mosaic as a nucleus for the hair-line crack, since on the pressure theory the pressure does not become appreciable, of course, until the temperature is below 250° C. and the presence of mosaic imperfections is therefore immaterial.

A more serious objection to the mosaic theory is as follows—the mosaic pattern is considered to be on the scale of the order of 1μ linear dimensions. When hair-line cracks occur, they are usually of the order of 1 cm. apart, and several centimetres long, a scale which is different by several orders of magnitude. γ iron in both the austenitic and ferritic conditions is considered to possess a mosaic structure, so that the mosaic structure cannot be the critical factor in the explanation as to why austenitic steels behave quite differently from ferritic steels in relation to hair-line cracks.

Mr. **T. M. Service** (Wm. Beardmore & Co., Ltd., Glasgow): I should like to congratulate both sets of authors on the excellent papers which they have presented. When reading them, however, the thought occurred to me that anybody who has been in the steel trade for any length of time knows that at one time nitrogen was blamed for all the ills in steel; then Sir Andrew McCance stated that non-metallic inclusions were to blame; and I believe Professor Andrew wrote a paper in which he showed that if we kept the phosphorus very low we got excellent steel. Between the wars the Germans started on oxygen, and that was considered to be the great source of trouble, and now we have come to hydrogen!

There are one or two points which I should like to put to Dr. Sykes and his co-authors. On page 157 they state that during the boil the hydrogen is low, but that it increases during refining, and then they refer to re-boiling. When they talk about re-boiling, I should like to ask what carbon they had in the bath when they started to re-boil; was it 0·35%, 0·5%, or 0·8%? We believe that it is not possible to get a boil with 0·35% of carbon, and it is very difficult to get an efficient boil with 0·5% of carbon, so that it would be interesting to know what the carbon was in the steel when starting to re-boil.

The authors give the figure for the hydrogen in the steel bath made in the arc furnace, and they give a similar figure for the open hearth, and the open hearth seems to be lower. Is there any reason why the open hearth should be lower than the basic electric? It is a little curious that in Germany, when making forgings for rotors, all the steel was made in the acid open-hearth furnace, though there was plenty of basic open hearth and basic electric. Why did they do that? Is it because the hydrogen is low, or is it a question of the method of working the furnace?

After the 1914–18 war, hair-line cracks were very bad, and my firm was as bad as anybody. We had a 3-ton Rennerfelt electric furnace in those days. In the Rennerfelt furnace the arcs do not go into the metal at all, but are 3 or 4 in. above the surface, like the gas in the open-hearth furnace. We made nickel–chromium steel. In those days molybdenum was not extensively used. We allowed the ingots to go cold without any treatment at all, and they did not have any hair-line cracks. We forged them, and carried out all sorts of fantastic treatments, and never at any time did they produce hair-line cracks. I wonder whether the authors have any ideas of why that should be so.

Dr. **S. A. Main** (Hadfields, Ltd., London): Mr. E. W. Colbeck regrets that he is unable to be here today to present comments based on work carried out in the Hadfields Research Laboratory, and has asked me to give the main points of what he wished to say.

The first point is that hydrogen undoubtedly plays a rôle in the occurrence of hair-line cracks. This has been demonstrated by various workers, and in one of our own experiments material rolled from an ingot into which hydrogen was blown during casting was absolutely "rotten" with snowflakes and hydrogen blow-holes, the rest of the cast being only moderately susceptible.

On the other hand, as shown by Dr. Sykes, the mere presence of hydrogen in steel will not cause hair-line cracks. This is also demonstrated by a further series of experiments carried out by Hadfields in which 3-in. and 4-in. square billets were heated in a hydrogen atmosphere at approximately 1000° C. for periods of up to 14 days. On air-cooling, billets of 1¼% chromium–molybdenum steel (0·56% of carbon) and 2¾% nickel–chromium–molybdenum steel (0·3% of carbon) were free from cracks. On the other hand, billets of 2½% chromium, 2½% nickel steel (0·3% of carbon) split from top to bottom. A billet of the 2¾% nickel–chromium–molybdenum steel when taper-quenched, *i.e.*, immersed in water to half its length immediately after withdrawal from the furnace, contained cracks varying in character from large quench cracks in the bottom portion to small internal hair-line cracks at the top (air-cooled) end.

If the actual amount of hydrogen present were the critical factor it would be expected that ere now someone would surely have obtained a correlation between hydrogen content and the incidence of hair-line cracks in rolled material. In our own experiments hydrogen contents of between 3·6 and 7·0 c.c./100 g. have been determined on samples taken from the ladle, cast into small (1½-in. dia.) water-cooled moulds, and water-quenched as soon as solid. No definite correlation was noted in the results.

Since the year 1921 a vast amount of work has been carried out by Hadfields on other aspects of the problem of hair-line cracks, and in attempting to correlate the accumulated data one point becomes quite evident, that is, the need for a standard test of susceptibility. Such a test would undoubtedly help, not only in determining the influence of hydrogen on the occurrence of hair-line cracks, but also of the effect of the different factors in steelmaking. Incidentally it would provide useful advance information to the works as to the susceptibility of the different casts going through for further manufacture.

In almost every series of experiments carried out some feature of the steelmaking has been found to be associated with the occurrence of hair-line cracks. Unfortunately the evidence has not been supported, and in some cases has been contradicted, in later experiments. This lack of correlation is perhaps not surprising when one considers the varied conditions of the experiments. The material examined has varied from pierced chill-cast ingots 6–15 in. in dia., to rolled or forged material of varying dimensions. The susceptibility has

been judged sometimes from the percentage of wasters, sometimes from the results of breaking-up individual piercings representing different casts, or, in the case of rolled material, from the results obtained on air-cooled samples taken during rolling.

The different casts have usually been segregated into two groups, sound and hair-line-cracked, the severity being largely ignored because of the great influence of the conditions in the operations subsequent to casting. Since the susceptibility of a particular cast to hair-line cracks is usually assessed on the basis of examination of material taken from production, it is hardly surprising that manufacturers have found difficulty in agreeing on the relative susceptibility of different types of steel.

The development of a standardized procedure would enable the severity factor to be taken into consideration, and if generally adopted would simplify co-operative work.

Preliminary experiments have been carried out by Hadfields, using for convenience standard 6-in. round moulds. The resultant blanks were forged to 4 or 3-in. square, air-cooled, and examined by supersonic means, transverse slices afterwards being examined magnetically. The test is apparently too searching in its present form, for almost every cast examined by this means showed susceptibility to some extent. Even a 0·55% carbon steel was found to be flawed. Where the results differed from those obtained in the rolled billets, the forged test was usually the more severely flawed.

Finally, and again agreeing with Mr. Burton, we found that the distribution of flaws in the forged billet shows a very interesting relationship to the flow of metal during forging. There is also a suggestion that the flaws occur more particularly where there is a high hardness gradient across the section.

It is hoped at some later date to present a paper on this subject.

Dr. Ing. **W. J. Wrażej** (Metallurgy Department, Royal School of Mines) : On page 178 of the paper by Sykes, Burton, and Gegg, the authors say : " No one has yet succeeded in producing hair-line cracks in austenitic steels, so that it is unlikely that the hydrogen concentration will set up cracks in the austenite." Again, on page 180 of the paper, they state : "The reason why hydrogen is associated with cracking in ferritic, but not austenitic and high-chromium martensitic, steels is a mystery. It might be argued in the case of austenitic steels that they are very ductile and do not transform on cooling, but such arguments do not apply in the case of high-chromium martensitic steels which, in addition, usually have hydrogen concentrations abnormally high compared with ferritic steels. The explanation of this anomaly might well throw useful light on the general hair-line-cracks problem."

Such frank statements as the above are only too rare in authoritative technical papers, for it seems seldom to be realized that the focusing of attention on these unexplained " mysteries " is the most direct means by which their true explanation may be achieved.

It is believed that the conundrum propounded by Dr. Sykes can be answered on the following lines.

The anomaly to which he refers may well be due to an incorrect interpretation of the nature of martensite and austenite. When considering the effects of quenching on steels, it is common to switch attention directly from atomic structure to grain structure, or even to actual sections of the metal, without giving due consideration to the possible importance of the intermediate conditions. Attention is transferred, as it were, from the shape of the pebble to the contour of the mountain.

My recent work on the mechanism of the γ-α transformation is now complete and under discussion, and will shortly be published. Heterogeneiety of the γ solid solution in carbon–iron alloys is deduced, and it is suggested that there are three pseudo-phases, the proportion of each depending upon the carbon content. One, called γG, is carbon-free and transforms into ferrite. The second, which is partially saturated with carbon and is called γS, transforms into martensite and contains one carbon atom associated with 24 iron atoms. The third, called γE, is saturated and has one carbon atom associated with 12 iron atoms. This undergoes no transformation and so persists as retained austenite.*

The diameter of a carbon atom (1·5 Å.) exceeds any of the available interstitial spaces in both γ- and α-iron unit cells ($a(1 - \sqrt{2}/2) = 1{\cdot}03$ Å. for γ, and $a(1 - \sqrt{3}/2) = 0{\cdot}39$ Å. for α), so either lattice will be distorted by the presence of a carbon atom. The distortion of an iron unit cell by a carbon atom will cause distortion to penetrate through neighbouring carbon-free iron unit cells in all directions until it is countered by the corresponding distortion from other carbon atoms. The effect of this distortion must be a tendency to form uniform distribution of the carbon atoms, giving a state of lowest free energy, and this must be the case in each of the pseudo-phases which form domains in a γ grain. In brief, the domains of particular pseudo-phases will be distinguished by uniform distribution of dissolved carbon atoms resulting from the relapse into the particular state of lowest free energy.

It is generally accepted that the austenite lattice allows room for foreign atoms to enter and form a solid solution. Hydrogen atoms, being small, will enter without difficulty and many can be accommodated with a minimum of distortion. Carbon atoms, on the other hand, as stated above, cause a distortion which is measurable, which can be confirmed by calculation and which displaces the iron atoms in adjacent unit cells. This distortion should allow additional room for the entrance of the small hydrogen atoms.

At room temperature, γ iron, with its more open lattice, would be expected to offer more room to hydrogen than would a ferritic steel, no matter whether this γ structure is due to the presence of alloying elements (*e.g.*, nickel or chromium) or to the retention of austenite as suggested above. Austenite changes only in parameter with a decrease in temperature and does not undergo transformation. Cooling will therefore have little effect upon the space available to hydrogen.

The martensitic structure is always accompanied by some retained austenite and there are many indications that the tetragonality of martensite is closely related to the amount of retained austenite. The ratio c/a in martensite increases with the quantity of retained austenite. This relationship has been demonstrated by many workers and is confirmed by my own experiments. Martensite is indisputably a distorted structure, and there should in consequence be ample room for the accommodation of hydrogen, even during the transformation from austenite (γS) into martensite.

In short, both austenitic and martensitic steels will provide more room for hydrogen than will ferritic steels. It may therefore be assumed that this ready accommodation of a relatively large amount of hydrogen will have no deleterious effect on the steel.

In the case of ferritic steels the transformation from γ into α iron cannot be prevented, for γG always transforms into ferrite. On transformation, however, the space available for hydrogen will suddenly diminish.

* W. J. Wrażej, *Nature*, 1946, vol. 158, Aug. 31, p. 308.

and if no time is available during cooling for the escape of hydrogen, the tesselated stresses produced by the hydrogen can exceed the strength of the material.

A grain of ferrite, like grains of other metals, possesses a mosaic structure with a disordered atomic arrangement at the interfaces, and here voids will be produced. These will also exist at high temperatures and, during cooling, there must be sufficient time available for their contained hydrogen to escape and leave room for the entrance of the hydrogen partly expelled from the transformed lattice; otherwise, pressure will develop in these voids which will then act as "micro-notches" between the grains, and hair-line cracks will develop.

The whole problem of the avoidance of hair-line cracks in steels is of great interest and is particularly attractive in view of the additional data now made available. Personally, I would like an opportunity to re-approach this problem in the light of recent investigations. Nevertheless, none of the valuable information provided by Dr. Sykes and his collaborators, by Professor Andrew and his collaborators, or by other workers, is contradictory to the explanation suggested above.

When engaged on the production of nickel–chromium steels before 1936, extensive experiments were carried out in which many casts of such steels were subjected to various conditions of plastic deformation.* These experiments led to conclusions which were published in Poland, and which proved satisfactory for the avoidance of hair-line cracks. An English translation was produced in 1943 and presented to the library of the Institute.

I wish to thank Professor C. W. Dannatt for his valuable help, criticism, and discussion.

Mr. H. H. Burton (English Steel Corporation, Ltd., Sheffield): My comments on the paper by Professor Andrew and his collaborators must be cut down to a minimum owing to lack of time. I should like to add my congratulations to the authors for contributing a paper of such great interest, containing so much careful work and thought and embodying a number of courageous and original ideas.

I was interested and surprised to find, however, that at the end of the paper the authors come to the conclusion that the hydrogen-pressure theory is the best means of accounting for hair-line cracks. It seems to me that their evidence, and indeed their argument, fits in just as well, if not better, with the idea that hydrogen embrittlement, combined with stresses due to various causes such as transformation, local segregation, etc., is the most likely cause.

My quarrel with the "pressure-in-voids" theory, however, is largely based upon some practical considerations. If we consider the hair-line cracks which only rarely are found in a cast material, such as an ingot, but which nevertheless are found occasionally, it is my experience that both the exposed surfaces of these cracks and also the rest of the fracture are always polygonal in character, in other words, they are intergranular. In an ingot which contains hair-line cracks but has not been reheated after cooling down from casting to a temperature sufficiently high to cause recrystallization, we can distinguish any hair-line cracks which have been found in the first place, say, by magnetic means, only by the increased brightness of these portions, as compared with the rest of the fractured face. If the fractured specimen is allowed to weather in air for a short time the difference in the appearance of the originally cracked and non-cracked portions disappears. On the other hand, if we take a similar specimen from the same ingot and refine it before fracturing, the polygonal appearance vanishes in the part where the hair-line cracks did not exist, leaving the cracked areas as before. It seems to me to be very difficult to imagine that there are voids in these polygonal grain boundaries. Professor Andrew and Dr. Lee saw a slide which I showed at a little talk which I gave at Sheffield University a few days ago, which shows these intergranular cracks as seen on a microsection and superimposed an etching which shows the primary crystallization, and there is no relation whatever between them. If there were any voids it seems to me reasonable to assume that the cracks would occur in some relationship with the primary crystallization, but apparently they do not.

Another objection is that if we consider the relative susceptibility of forged and rolled billets made from the same steel we find that forging, which always welds up the measureable voids—and presumably also the invisible voids—near the axis of the billet much more effectively than rolling, produces material which is far more susceptible to hair-line cracks near the centre of the section than rolled material of the same size. Furthermore, in the rolled material the hair-line cracks which do form occur much more extensively in that region of the cross-section of the billet where we would expect the maximum soundness and where this condition is actually achieved, as judged by transverse tensile testing.

Mr. **D. A. Oliver** (Messrs. Wm. Jessop & Sons, Ltd., Sheffield): We have a mine of information in these two papers, but I shall confine my remarks to particular points. With regard to the paper by Professor Andrew and his colleagues, I feel that the discussion of results in that paper does not do justice to the factual character of the earlier part of it. Speculating in print is rather dangerous, especially as some of us have been impressed by the ideas put forward in Professor Andrew's previous papers and feel reluctant now to discard them completely. Moreover, I consider that in demolishing some of his earlier explanations he has not done justice to all the considerations. Perhaps, therefore, we have yet to receive from Sheffield University a critical summary of what they finally believe.

It is clear that in this new paper there is less emphasis on the rôle of retained austenite. I still think that films of retained austenite can play an important part, and that the strains that occur in a cooling mass of steel play a critical part. In other words, if the films of retained austenite enriched by hydrogen, or, if the films of alloy segregate embrittled by hydrogen, are present in the steel which is undergoing a certain amount of shear, it is obvious that those brittle films will be expected to rupture, and new cracks to relieve the internal stresses suddenly produced will occur more or less at right-angles, and we shall get something like our characteristic pattern. I think that nearly all the ideas which have been put forward play a part, but we need to be increasingly critical in ascertaining "causes."

On page 251 of the paper, tesselated stresses are mentioned as facilitating the decomposition of "cementite." I should appreciate a little illumination as to the exact meaning of that phrase, and as to whether "cementite" is the word intended or whether it should be "austenite."

On page 252, where the "voids" and "cavities" are referred to, I should like to say that I do not think that a cavity which is just large enough to take one hydrogen molecule is sufficiently large to start the process of

* W. J. Wrażej, *Hutnik*, 1936, vol. 9, No. 1, pp. 5–12.

pressure build-up. I visualize that any cavity worthy of the name would, at least, have room for an adsorbed monomolecular layer of hydrogen, or even more layers than one, together with enough space for a hydrogen molecule to vibrate over a sufficient amplitude with reasonable freedom ; because when we are talking about gas pressures we are really dealing with the impact of gas molecules on the walls of the postulated enclosure.

The reference to methane as a possible agent is well known in the literature, and has, of course, been emphasized by the German workers, and elaborate theories have been worked out with regard to it. I feel that at this date one should either reject or accept the hypothesis and discuss the evidence for it.

I hope that these comments are not regarded as too critical, but they are submitted to help to clarify our ideas as to just what in fact is happening.

Coming now to the paper by Dr. Sykes, Mr. Burton, and Mr. Gegg, I found this safer in its attempts to theorize and satisfying in its emphasis on facts. However, I looked at once for evidence in the hydrogen measurements of how rapidly the hydrogen diffused out of the test-piece when cut from an ingot or billet, and I could not find a curve showing the order of error to expect if one trepanned out a $1\frac{3}{4}$-in. specimen on a particular day of the week and tested at differing periods later. A reply to that question would increase the value of the work, as the authors have ventured the remark in the paper that most of the solid-steel estimations can probably be relied on to 0·5 c.c., although this is presumably independent of the time effect. On the liquid-steel determinations I believe also that no error is precisely stated.

I consider that the question of whether hydrogen segregates is not yet answered with certainty. If we take a large test-piece from different positions in an ingot we can certainly say, after test, that the average hydrogen content estimated at different parts of the ingot is much the same. From such results we can deduce that there is no macro-segregation, but I believe that there must be micro-segregation, and we are indebted to some earlier work of Professor Andrew for pointing out that hydrogen in certain circumstances might be a powerful segregating element. From the practical point of view I have some evidence which seems to support that view. In manganese–molybdenum steels, when there is dampness in the ingot head or undue hydrogen in the melt, we get banding in the microstructure which is rich in manganese–molybdenum–iron complex carbides. The alloy banding does seem to occur in the presence of high hydrogen in the melt at the time of casting, which would show that on a small scale at any rate hydrogen may function in some peculiar way to cause alloy segregation on a relatively small scale, although the average over a volume may be fairly constant. I should therefore like to ask the authors whether they agree that they are concerning themselves only with macro-segregation, as distinct from micro-segregation.

The authors have been too modest on the question of heat-treatment cycles to avoid hair-line cracking. It is well known that during the war this question of hair-line cracks loomed extremely large, and I was indebted to Mr. Burton for valuable advice on possible heat-treatments to eliminate hair-line cracks. We extended that work as vigorously as we could, with very great advantage. Without going into details, I may say that we did arrive at one very interesting state of affairs. In a particular continuous production of alloy-steel forgings we found that we could adopt an anti-hair-line-crack heat-treatment after forging, which took 110 hr., and we secured something like 98% effectiveness ; but if we reduced that period to 96 hr., just hurrying the whole process up a little, we got only about 80% successes, so that we had to revert to the slightly longer time cycle. It seems, therefore, that there is a critical minimum period over which these heat-treatment cycles should be operated for a particular works practice, and I should like to pay a cordial tribute to the information that is perhaps rather modestly concealed in this paper.

I found the section dealing with diffusion very interesting, and I should like to ask whether we are justified in making the following deduction from it. The simple diffusion theory is based on a postulated perfect lattice. Does it mean that the fact that we can get agreement between alloy steels and pure iron and that we can link up with Sievert's work and the more recent work of Smithells and Ransley, tends to discount the powerful rôle of fissures, cracks, and grain-boundary diffusions ? One might say that the grain boundary in pure iron is similar to that in a steel full of other impurities, and also that alloys do not affect diffusion very much ; but I should like to know whether the authors feel that the fact that there is agreement between these diffusion calculations, based on fairly fundamental constants, more or less rules out some of the alternatives. Smithells and Ransley imagine a hydrogen atom diffusing through a metal lattice by being interstitial for part of its route and nudging an atom to one side and getting past, and that is why the diffusion of hydrogen atoms through a metal lattice is of a very different order from that of atoms which are larger.

Finally, there is the mystery of why ferritic steels are subject to hair-line cracks but austenitic steels are not. Is that mystery heightened by ruling-out altogether the possibility of films of retained austenite in ferritic steels which on transforming create stress by volume changes ? I do not feel I am justified in trying to discuss here the borderline case of the high-chromium steel.

CORRESPONDENCE

Dr. **H. Lee** (Sheffield University) wrote : I wish to congratulate Dr. Sykes, Mr. Burton, and Mr. Gegg for what I think is a very fine piece of work written and presented with an impartial and open mind. Their work is all the more valuable because the experiments were carried out on a large scale and the data crystallized more or less directly from the normal industrial practice. In paying this tribute, I have a further point to make, *i.e.*, the authors have demonstrated in the most candid manner their effort to bridge the gulf between academic and industrial researches and to a large extent they have succeeded. This, to my mind, is a very noble service in itself.

For seven or eight years Professor Andrew, my other colleagues, and myself have been working on a similar subject at Sheffield University. We have shown that hydrogen is detrimental to the properties of steel and that the removal of hydrogen is governed by the temperature, time, and mass and is closely related to the transformation characteristics of the steel. In our experiments small specimens were employed and hydrogen was introduced into the specimen by artificial methods. Because of the small size of our specimens, the cooling rate which we employed in order to retain hydrogen and to produce internal cracks in the specimen had to be accelerated. The result was that in many cases cracks in our specimens appear in a pattern somewhat different from those encountered in industry. This difference has been repeatedly pointed out and held by many people to cast doubt on whether hydrogen is the real cause of hair-line cracks.

The paper by Sykes, Burton, and Gegg is therefore both timely and welcome, especially to those who are working on the same problem. Having only laboratory facilities at their disposal, academic workers like myself and my colleagues are not in a very good position to offer what other people would accept as convincing evidence from the practical point of view. With much valuable information now available from the authors' paper, it gives my colleagues and me much comfort and pleasure when we compare some of their results and general conclusions with our own.

Although the authors have not declared emphatically that hydrogen is the fundamental or even the major cause of hair-line cracks, they have nevertheless stated quite definitely that material containing hydrogen will be more prone to cracking in practice. These words, coming from outstanding steelmakers, as are the authors, are particularly significant and will go a long way in settling some of the controversies. The authors have also confirmed the results that hydrogen can cause an embrittling effect and that the ductility of the steel is improved if the hydrogen is removed. In the same connection, we have also shown that if a steel is contaminated with hydrogen, the reduction of area is usually more seriously affected than the elongation. Another important point where our results are in complete agreement is the fact that the composition and the treatment of the steel are very important and the hydrogen content alone cannot be taken as the sole criterion in determining hair-line crack formation.

Turning to the question of hydrogen removal, I am extremely pleased that our results obtained on small specimens artificially impregnated with hydrogen have been shown by the authors to be of general application in industrial practice. I agree with the authors that the limiting value which we have shown in our equation governing the removal of hydrogen from steel may be largely imposed by the uniform distribution of hydrogen in our specimens at the initial stage of the experiment. When this stage is over and when the " steady " conditions are set up, our results could then probably be fitted in with a simple exponential equation.

Having summed up these points on which we are in agreement, I should like to ask the authors a few questions. The first question is concerned largely with certain discrepancies in some of the hydrogen figures as given in the paper. These are as follows :

	Billet No.	Treatment	Hydrogen, c.c./100 g.
Table XI	*J*2	Pit-cooled	2·6
	*J*3	Pit-cooled, heated to 650° C. for 3 hr., A.C.	3·8
Table XII	*B*3	Pit-cooled, reheated to 650° C. for 1 hr., W.Q.	7·8
	*B*4	Pit-cooled, reheated to 650° C. for 1 hr., A.C.	9·6
	*R*1	Hot from rolling to furnace at 650° C., held for 4 hr., cooled to 500° C. in 3 hr., A.C.	12·0
	*R*2	As *R*1, but water-quenched from 500° C.	10·6

Taking into account the adjacent position in which these billets were cut from the respective ingots and the subsequent treatments given to them, one would expect that the hydrogen content of *J*3 would be lower than that of *J*2. That of *B*3 and *R*2 should be nearly the same as, if not slightly lower than, that of *B*4 and *R*1 respectively. However, the results as given indicate just the reverse. Similarly, it is difficult to account for the big difference in the hydrogen content between *G*4 and *G*3, given on p. 168 as 4·3 and 10 c.c./100 g., by the difference in hydrogen diffusivity between 1200° and 1000° C., because the time of treatment was only 1 hr. I have noticed that on p. 166 the authors have stated " . . . the gas extracted from a number of the samples was collected and analysed for hydrogen—these tests showed that 95% of the gas extracted was hydrogen." This statement rather gives me the clue to think that some of the discrepancies in their hydrogen results as listed above might have arisen from the omission of the gas analysis. In my own experience I have found it necessary to collect and analyse a gas sample in every hydrogen determination. The hydrogen content of the hot-extracted gas could vary by anything from between 60 to nearly 100%, although I support the authors' statement that in the majority of cases the samples are more than 90% pure. The variation in the purity of the hot-extracted gas was found even with trepanned specimens from the works. Another possible explanation of these results is, of course, the question of hydrogen segregation. This has been shown by the authors to occur in ingots where alloy-segregation and difference in porosity between top and bottom are apparent. The question remains, however, whether hydrogen-segregation could occur to any appreciable extent in forged billets.

The next point is the more fundamental question concerning hydrogen diffusion. In correlating the solubility results by Sieverts, and the permeability results by Smithell and Ransley, both worked on pure iron, the authors have calculated the value of hydrogen diffusivity in α iron for different temperatures. These values have been used to compare with the permeability results obtained on a nickel–chromium–tungsten steel by Bennek and Klotzbach (Table XIV). Because the change in permeability for the nickel–chromium–tungsten steel with temperature is large, being of the order of 20 : 1 in the range 300–600° C., and the change in diffusivity for pure iron is small, being about 2 : 1 in the same temperature range, the authors jump straight to the conclusion that the major contribution in improving the permeability comes from the increase in solubility. To my mind such a conclusion is not justified. First of all, since the compositions of the iron and the steel in question are different, there is no reason to suppose that the temperature coefficient of hydrogen diffusion of these two should be the same, especially in the α state. Bearing this in mind, the whole weight need not be thrust upon the difference in solubility. Moreover, in order that these results can be accounted for on the basis of difference in solubility alone, as the authors assumed, it would mean that the difference in hydrogen solubility between the pure iron and the nickel–chromium–tungsten steel in question in the α state at 300° or 600° C., one way or the other, must be of the order of 10 : 1. On the other hand, the authors have quoted the solubility results for pure iron and for low-alloy steels in the γ condition at 950° C. and indicated that there is no appreciable difference between them. It is therefore rather difficult to imagine that in the α state at 600° or 300° C. there should be a tenfold difference between the iron and the nickel–chromium–tungsten steel.

With regard to the anomalous variation in hydrogen diffusivity in steel at low temperatures, say, below 350° C., the authors have adopted the right attitude to discuss this point with an open mind. They have smartly and rightly disposed of the idea of a threshold pressure, but at the same time it seems that they were unable to make up their mind between activated surface adsorption and the assumption of a weak bond existing between iron and hydrogen at low temperatures. While

the actual mechanism of activated adsorption is still relatively obscure, and those who advertise this may easily over-stress its importance, the idea that a weak bond exists between iron and hydrogen has no direct experimental proof. In a recent paper by Professor Andrew and myself, it has been assumed that there is a critical temperature below which the mosaic behaviour of iron crystals becomes apparent, and this temperature may vary with the composition and structure of the steel. This idea appears to be feasible, because the existence of mosaic structure in metals and alloys at room temperature has been widely accepted and the size of the mosaic "blocks" is known to vary with the metal and the temperature. The question that I wish to ask the authors is whether, in their opinion, the development of mosaic structure below a certain critical temperature could possibly be linked up in some way with the observed anomalous variation of hydrogen diffusivity in iron and steel.

Referring to the formation of hair-line cracks, I am glad that the authors have agreed in principle that very high hydrogen pressures could be set up in steel. The order of the pressure which the authors have given for a hydrogen content of 6 c.c./100 g. is, however, many times more than that of which I dare to think. In iron and steel there are various kinds of voids or cavities and, depending on the amount of cavities present, the pressure that could be built up for a given hydrogen content must vary. The relative non-susceptibility of the high-chromium martensitic steel, as pointed out by the authors, might possibly be linked up with this. With regard to austenitic steels, however, there is no reliable data for the solid solubility of hydrogen at room temperature, and I am inclined to think that the actual solubility might be very much higher than that obtained by extrapolation.

Finally, I should like to emphasize two important facts which are clearly pointed out by the authors in their excellent paper, *viz.*, the absence of hair-line-crack trouble in small sections in works practice, and the relative non-susceptibility of cast steels as compared with forged billets. These two facts are fairly well known in industry. It seems to me that they fit in very well with the hydrogen cavity-pressure theory, but I doubt if they are in line with if not contrary to the view that micro-segregation and transformation stresses are chiefly responsible for hair-line-crack formation in steel.

Dr. **N. J. Petch** (Cavendish Laboratory, Cambridge) wrote: Sykes, Burton and Gegg are particularly interested in the high-chromium martensitic steels. While I have no detailed knowledge of these, I would suggest the possibility that the high-alloy content may lead to a fairly uniform transformation, so that, although there is high hardness, the localized stresses may be less than in steels of lower alloy content. In this way the freedom from hair-line cracking could be explained.

Dr. **J. E. Hurst** and Dr. **R. V. Riley** (Staveley Coal and Iron Co., Ltd., near Chesterfield) wrote: It is considered of some importance that the limit of hydrogen content, consistent with good ductility in steel, is stated to be 2 ml./100 g. This self-same limit of 2 ml./100 g. for hydrogen is also of importance in the production of castings in high-silicon iron of acid-resisting quality. It may be said that this 15% silicon iron in some ways resembles steel more than it does iron; it has a carbon content of less than 1%, low sulphur and low phosphorus percentages, large shrinkage on solidification, and it is frequently made in a batch-type furnace. Therefore it is an interesting coincidence that the limiting figure applies in both cases.

If substantially more than 2 ml./100 g. of hydrogen are present in molten silicon iron, the castings made from it will tend to contain blow-holes. If the hydrogen is removed from the iron before casting to a value of less than 2 ml./100 g., then it is unlikely that porosity troubles will occur.

It may sometimes happen that a casting made from metal containing hydrogen in excess of 2 ml./100 g. is not affected by visible porosity. The casting in this condition frequently becomes heir to a foundry defect, described by us as "spontaneous cracking," which may occur shortly after stripping from the mould, during machining, or in storage some weeks later. This defect appears to us to be similar to that of hair-line cracking in steel. For example, the crack occurs at sections of maximum stress, it frequently takes place after an induction period, it is transcrystalline, and finally the incidence of cracking may be checked by a soaking at 800° C. for a period of time depending upon the cross-sectional area of the casting. Castings which are made from metal containing less than 2 ml./100 g. of hydrogen seldom crack spontaneously; similarly it is found that with equal hydrogen contents the casting containing the most visible unsoundness is least prone to spontaneous cracking.

These experimental observations based upon vacuum-fusion analyses and rigid foundry control in the case of silicon iron appear to fit into the framework of the hydrogen-pressure theory as applied to the problem of hair-line cracking in steel. It is suggested that the conditions attaching to the observed cases of hair-line cracking in steelmaking may bear comparison with this simple illustration of the effect of hydrogen on the founding of a commercially difficult cast iron.

AUTHORS' REPLIES

Dr. **H. Lee** (University of Sheffield), replying to the discussion on the paper by Professor Andrew, Mr. Lloyd, Mr. Stephenson, and himself, said: I should like to thank all the contributors to the discussion for their kind and stimulating remarks. There are a few specific points which I should like to deal with here; to other comments we shall have to reply by writing. Dr. Sykes asked why the rate of diffusion and the apparent solubility of hydrogen vary with the structure of the steel in the α state. If I wished to be dogmatic, I would probably return the question by saying "why not?" I think, however, that the reason may be looked upon as follows. In steel in the α state there are two major constituents, cementite and ferrite. It seems logical to assume that the diffusion of hydrogen through the mass will vary with the distribution and the state of division of the cementite particles or lamellæ. From a theoretical and mathematical-analogy point of view, Dr. Sykes himself used the differential equations of heat flow to calculate the rate of hydrogen diffusion. I need hardly say that the equations of heat conduction are similar to those governing the conductivity of electricity. I draw attention to this because as far as I know there are no available data showing that heat conductivity is different with different structures, but we do know that electrical resistivity is structure-sensitive.

With regard to the question of "apparent" solubility, personally I regard this as being linked up with the presence of internal cavities in steel. The word "cavities" applies to large blow-holes as well as submicroscopic "voids." There is reason to believe that the latter do exist in steel, and if they can be identified with mosaic disjunctions, they will probably vary with the composition and treatment of steel. If you accept this view, it will help to explain that the "apparent" solubility of

hydrogen in steel at room temperature depends upon the composition and treatment of steel.

Dr. Sykes, quite rightly, raised the point about mosaic boundaries, and he asked why they should be apparent only below a critical temperature. Dr. Sykes expressed the view that the main reason for assuming mosaic structures in metals is based upon X-ray reflection, but the intensity does not vary anomalously with temperature. As far as I am aware, there is another strong reason for the assumption of mosaic structures in metals. Some five or six years ago, Sir Lawrence Bragg showed clearly in a public lecture that it is necessary to assume the existence of imperfections in metal crystals, which is the equivalent of the mosaic idea, to explain why with a metal the tensile strength as found in practice is far below that arrived at by theoretical calculation. For example, with copper or iron, the theoretical strength may be of the order of 1000 tons/sq. in., a figure which is a hundred times greater than that met with in practice.

Mr. Oliver asked us for a critical summary of our views. In answer to this request, I may refer him to a recent paper by Professor Andrew and myself, published in the Symposium on Internal Stresses, organized by the Institute of Metals. It is a good summary of our views about the problem concerned.

Mr. Oliver complained that we have rejected some of our earlier ideas. This we regret as much as Mr. Oliver does, but, in keeping with the scientific spirit, when new facts come to light as time passes on, it is sometimes inevitable that one has to modify one's own views.

On the question of retained austenite, I can quite imagine that it may happen in a quenched steel. In a big mass normally encountered in steelworks, where the treatment at low temperatures may go on for hundreds of hours and during which the steel should be completely transformed, I fail to see how any retained austenite could be left in the specimen after cooling. If, however, it can be shown that in all cases hair-line cracks occur only when retained austenite is present, I shall be quite prepared to accept the retained-austenite theory.

Mr. Oliver quoted a passage from page 251 where he thought that " cementite " should read " austenite." I agree that it could apply to austenite, but in this particular sentence we definitely meant it to be cementite. Our view is that under certain conditions of stress the cementite is probably rendered a little more unstable. Regarding the question of cavity pressures connected with only one molecule of hydrogen, I do not think Mr. Oliver's point is relevant because in the text we referred to " . . . more than one. . . ."

Referring to methane, we believe that under certain favourable conditions the methane reaction may come in, but we do not regard it as essential for hair-line crack formation. In other words, methane reaction may be a contributing factor, but does not afford a general explanation of the hair-line crack problem.

Professor **J. H. Andrew** and his co-authors, in a further reply, wrote: Mr. Honeyman asked us to explain the white streaks which we found in hydrogen-soaked and water-quenched specimens as described in one of our earlier papers. The answer is that, in our opinion, they were retained austenite. The presence of retained austenite in quenched steels would not be an unusual feature, and Mr. Honeyman may remember that in the same paper white streaks were also reported in nitrogen-soaked and water-quenched specimens. By comparison with the hydrogen-soaked specimens, the white streaks in nitrogen-soaked specimens were found to be fainter and fewer, but this apparent difference may be due to the possible different chemical behaviour towards etching of the austenite with hydrogen from that without. Whilst we do not deny that hydrogen-rich austenite could exist in quenched steels, we disagree with Mr. Honeyman that austenite must also be present in isothermally transformed or slowly cooled specimens and is directly responsible for hair-line crack formation. There is no direct evidence that could be shown to support the latter view and we would refer Mr. Honeyman to our earlier reply to Dr. Petch's contribution on this point. Even in quenched steels, we do not believe that the formation of cracks is the result of the decomposition of the hydrogen-rich austenite *in situ*, because the cracks are invariably radial and confined to an annular zone whereas the white streaks were found to be more or less evenly distributed throughout the specimen.

Dr. Sykes' question on the best possible way of removing hydrogen from steel is too big a subject for anyone to answer satisfactorily. However, we can offer certain suggestions and briefly state our views. We still believe that a complete transformation followed by reheating and soaking at the highest possible α range will give the highest efficiency in hydrogen removal. The steel should be in a fully softened condition, preferably with the cementite as round particles rather than as lamellæ, for we have certain indications that, at room temperature at any rate, cementite lamellae may hinder hydrogen diffusion. Other things being equal, such as composition and structure, etc., we think Dr. Sykes is right in saying that the softer the specimen, the greater will be the hydrogen permeability.

We are inclined to think that, apart from the hypothetical mosaic disjunctions, certain parts of crystal boundaries, inter-phase boundaries, or similar discontinuities in the mass could be effective in acting as " voids " or cavities for the storage of molecular hydrogen. The nature of such boundaries or disjunctions is very obscure, and we are not in a position to make any definite comments. We believe that the apparent solubility is closely connected with the amount of cavities or " voids " present, and they are assumed to vary with the treatment of the steel. We fail to see how chemical combination between iron and hydrogen can be altered by treatment if we accept Dr. Sykes' suggestion that the apparent solubility may be due to some chemical combination. The idea that mosaic structures in metal crystals become apparent only below a certain critical temperature is, of course, speculative, but it is no more speculative than the suggestion that a chemical bond begins to develop between iron and hydrogen below a certain temperature. Both are extremely difficult to prove or disprove.

We do not think the fact that the mosaic pattern is of the order of 1μ dimensions, whereas hair-line cracks are usually 1 cm. or more apart, as pointed out by Dr. Sykes, is a serious objection to our theory. We have repeatedly pointed out that stresses determine the distribution of hair-line cracks in steel, hydrogen pressures and the stresses being additive. In speaking of internal stresses, one might alternatively talk in terms of local " weakness " in the mass. The local weakness of the material would of course vary with the conditions but is unlikely to be separated by 1μ dimensions only.

Mr. Colbeck and Dr. Main urged the device of a standard test for hair-line crack susceptibility. We agree that it is a task which the steelmakers may have to face in the near future.

We are very much interested in Dr. Wrażej's idea, and we shall look forward to reading his paper.

We appreciate Mr. Burton's remarks and the interest which he has taken on the hair-line crack problem. Mr. Burton's view on hair-line cracks being due to hydrogen embrittlement combined with stresses goes

only half-way, because the cause of hydrogen embrittlement has been left unexplained. If Mr. Burton accepts our explanation that hydrogen embrittlement is caused by cavity pressures, then we are in complete accord with each other. In our opinion, Mr. Burton's experience on cast, rolled, and forged material in the order of increasing susceptibility fits in very well with the cavity-pressure theory, because as the porosity or the amount of cavities is reduced further and further, less and less hydrogen will be required to build up the disruptive pressure.

Mr. Oliver's various points have been dealt with in the verbal reply.

We are glad that Dr. Hurst and Dr. Riley were able to offer evidence in support of the hydrogen-pressure theory in their experiments on cast iron.

Dr. **C. Sykes,** F.R.S., Mr. **H. H. Burton,** and Mr. **C. C. Gegg** wrote in reply : The discussion of the paper brings out very clearly that there is still little unanimity regarding the origin of hair-line cracks, although it appears to be generally agreed that hydrogen is one of the significant factors.

Mr. Honeyman favours the retained-austenite theory, and asks what evidence there is to refute the suggestion that the incubation period is due to the gradual transformation of minute traces of austenite at room temperature. It is admitted that there is no positive evidence in the paper to disprove the idea that the incubation period may be linked up with the transformation of retained austenite at normal temperatures. On the other hand the retained-austenite theory cannot at present be accepted, as no evidence has yet been found of retained austenite on examination of cracked material by X-ray methods. Furthermore, in most cracked material it is not possible to find traces of martensite, which would be the decomposition product of retained austenite transforming after cooling down to room temperatures. The specimen *R*2, which is described in the paper as containing martensite, was cooled under abnormal conditions, and this structure is not at all typical of material, especially material of large size, which is found to be hair-line cracked in works practice. It can be argued, of course, that the usual methods of examination are probably sensitive to only 5% or less of the bulk and might miss the minute traces, but on general grounds it seems highly unlikely that much of the material in which cracks are found has contained austenite at the stage when cracks occurred.

Mr. Honeyman rightly emphasizes that the transformation characteristics of hot-worked material may be different from that of the same material austenitized at lower temperatures, say, 850–900° C. There is an important difference here, material austenitized at 1200° C. being in general less readily transformed, particularly in the pearlitic range.

In the martensitic steels we referred to steels of the 12–14% chromium type and the 18% chromium type which transform at 250–100° C. when allowed to cool in the moulds after casting. Ingots may clink, but hair-line cracks have not been reported. The 18% chromium type will not transform in the pearlitic range at all, and must be cooled usually to about 100° C. before transformation occurs, yet although hydrogen contents are much higher than in the low-alloy steels, there is no record of forgings giving trouble due to hair-line cracks, and no precautionary treatments are given.

Mr. Service lists all the *bêtes noires* of the steelmaker past and present, and is doubtful whether the latest addition, hydrogen, will be any more permanent than the rest.

The carbon at the start of the re-boil in the heats referred to in the paper was 0·20–0·25%. There are several possible reasons why basic electric steel is generally higher in hydrogen than is an open-hearth steel ; perhaps the two most likely are (*a*) more lime is used in the electric furnace, and (*b*) ionization in the arc increases the effective hydrogen pressure.

On the question of the Rennerfelt ingot it can be argued that there are just as many reasons why certain pieces of steel are free from hair-line cracks as to the contrary. In fact, it is not clear from Mr. Service's description what tests were made to prove that the *ingots* were free from hair-line cracks. With such small ingots it is not excluded that the ingots were cracked and the cracks welded up during forging.

Dr. Main has reviewed briefly some of the experimental work carried out by Messrs. Hadfields, Ltd., on the hydrogen problem. As members of the Hair-Line Crack Committee we have had the privilege of discussing this work from time to time. The development of a standardized procedure to assess the relative susceptibility of different casts would be of great practical value. At the moment no such test exists, apart perhaps from the value of the hydrogen content of the liquid steel in the ladle.

Dr. Wrażej points out that the solubility in austenite is likely to be greater than in ferrite, since there is more space in the face-centred lattice than in the body-centred lattice. This is true, and is borne out by the actual solubility figures measured by different investigators. As given in the paper, the difference in solubility at any given temperature, depending on whether the steel is austenitic or pearlitic, is about 30%, and the resulting equilibrium pressures are in the ratio of 1 to 2. Thus, for 6 c.c. of hydrogen the equilibrium pressure at room temperature is about 1×10^3 tons/sq. in. for the pearlitic steel, and 6×10^5 tons/sq. in. for the same steel in the austenitic condition. Consequently, whilst it is true that the austenitic condition is favourable to reducing the hydrogen pressure, the difference hardly seems sufficient to account for the elimination of cracking.

As we see it, according to Dr. Wrażej's explanation and the known solubility data, an austenitic steel with 8 c.c. of hydrogen per 100 g. should behave similarly to a pearlitic steel with 6 c.c. of hydrogen per 100 g. This is not the case. It may be that the solubility data are not accurate, but until further data are forthcoming we favour the view that the enhanced " tri-axial " ductility and low yield point of austenitic steels is at least one of the important reasons why austenitic steels are immune from hair-line cracks.

Mr. Oliver, in our opinion, has emphasized the importance of being clear as to what is meant when voids and cavities are mentioned. The state of disorder at a normal grain boundary, etc., can hardly be classed in the same category as a void in which a definite pressure can be established. The methods used for hydrogen estimation are those described by Wells and Barraclough (*see* reference 7 and page 157 of our paper).

The work on diffusion does not rule out the possible importance of voids, and the hydrogen-pressure theory. Thus, taking equation (3) of the paper, the equilibrium pressures are for 6 c.c. of hydrogen per 100 g. dissolved.

Equilibrium Pressure Corresponding to 6 c.c. of Hydrogen per 100 g.

Pressure, tons/sq. in.	Temperature, °C.
5	350
10	300
40	250
200	200
1×10^3	150
1×10^4	100
1×10^6	27

Thus it is not until the temperature gets below 250° C. that any appreciable pressure can be built up and this conclusion depends only on equation (3) being correct and the hydrogen being present. It is independent of the assumptions made relating to diffusion.

On the question of hydrogen segregation, there appear to be two main possibilities and a pseudo-possibility. Firstly, there is macro-segregation due to the difference in solubility in liquid and solid steel at the melting point. So far the evidence as to the magnitude of this effect is inconclusive, and since more measurements are in hand the matter can be left. Micro-segregation due to changes in solubility arising from segregation of alloying constituents in normal ferritic alloy steels is likely to be small since when Bennek and Klotzbach examined the solubility of six different steels at 950° C. the variation was ± 10%.

If, however, one believes the hydrogen-pressure theory, a form of segregation should exist which is really dependent on the scale of size of the sample. The pressures referred to in the table above are those which would be generated in a cavity sufficiently small for the hydrogen content to have a negligible effect in reducing the hydrogen content of the surrounding material. It is not always realized that the absolute volume of cavities must be very small if the theoretical pressures are to be attained. Thus, if the volume of cavities is 1 part in 10,000, then the equilibrium pressure in the cavities is reduced from 10^6 tons/sq. in. to about 25 tons/sq. in. ; practically the whole of the hydrogen ($> 99\%$) is in the cavities and practically none is in the steel. It is not easy to prove or disprove whether the density of a forging deviates from the theoretical by 1 part in 10,000. Now let us suppose that whilst on the average the amount of cavity is 1 part in 10,000, there is a statistical variation and that in two small specimens cut side by side the cavity in one is 1 part in 5000 and in the other 1 part in 20,000 ; then provided that the cavities are reasonably well distributed, *i.e.*, not on the surface, our hydrogen-extraction apparatus will find 12 c.c./100 g. in one specimen, and 3 c.c./100 g. in the other.

The above rather exaggerated example is taken merely to show that if the hydrogen-pressure theory is sound, segregation will occur at temperatures below 250° C. if the steel is not completely homogeneous, or if the " cavities " are not distributed in such a way that the statistical variation is small in volumes of, say, 1 c.c., comparable with the hydrogen test-piece. If there is such a statistical variation, results from samples cut from larger pieces may give quite misleading results as to the average hydrogen content and indicate a segregation from point to point which is a function only of the soundness of the steel.

We were pleased to hear of Mr. Oliver's satisfactory experience with precautionary treatments of the type mentioned in the paper.

Dr. Lee has referred to certain discrepancies in the rate of hydrogen removal. We agree with his criticism, but would emphasize the following points. The hydrogen figures, in our opinion, represent the hydrogen contents of the billets as measured in the normal manner and can be correlated with the state of the billets whether cracked or uncracked. They were used only to show that the hydrogen content, as determined by the extraction method, is not the only criterion which decides whether steel is hair-line cracked or not. From time to time we have analysed the gas extracted and have always found a hydrogen content in excess of 90%. This analysis was not made on all the samples used in the paper, but we doubt very much whether the discrepancies to which he refers could be explained on this account. Segregation and variability in treatment are more likely. The only heat-treatments which in our opinion were sufficiently well controlled to be used for diffusivity estimations are those recorded in Fig. 20.

Dr. Lee has misunderstood the section on diffusivity. The diffusivity figures given in Table XIV are calculated from solubility data by Sieverts and permeability data by Smithells and Ransley, both for *pure iron*.

Restricting the argument only to pure iron, we have a change in diffusivity of from $1{\cdot}00 \times 10^{-4}$ at 300° C. to $2{\cdot}3 \times 10^{-4}$ at 700° C. (*see* Table XIV). The change in permeability, equation (4), which is an experimentally determined equation, from 300° to 700° C., is in the ratio 1 to 31. The change in solubility in pure iron is given by equation (3) and is 1 to 13·7.

Thus an increase of a factor of 31 in permeability is made up as to a factor of 2·3 in diffusivity and 13·7 in increase of solubility, which is in agreement with the statement criticized by Dr. Lee.

The permeability figures given in Table XIV for the nickel–chromium–molybdenum steel show that the permeabilities at 300° C. and 700° C. are in the ratio of 1 to 33—very similar to the pure-iron value—and were included for the express purpose of showing, within the limitations stated in the paper, that Bennek and Klotzbach's results for alloy steels were very similar to those recorded for pure iron.

We doubt whether there is any relation between anomalous diffusion and mosaic blocks ; actually there is no evidence that the mosaic structure varies peculiarly at temperatures below 350° C.

Dr. Lee mentioned the two facts (1) that small sections give little trouble due to rapid hydrogen loss, and (2) that cast metals are relatively immune. We agree that this latter experience supports the cavity theory. Our difficulty with the hydrogen-pressure theory is that it is so very difficult to prove or disprove. Thus one says that the reason why cast materials are immune is because they contain too many cavities, say, $>$ 1 part in 10,000, whereas forged materials are cracked presumably because they contain $<$ 1 part in 100,000. Similarly, forged bar perfectly free from cavities would not crack because it contained no cavities. Apart from the further difficulty with austenitic steels, to which we refer in the paper, another objection we have to the theory in its present form is that every piece of steel should crack—most steel contains at least 0·2 c.c. of hydrogen, and the corresponding equilibrium pressure is 1000 tons/sq. in. at room temperature. This should crack any steel.

The theory is very attractive in many ways ; it would explain the incubation period very nicely, but before it can be accepted some experimental work needs to be carried out to bring it into line quantitatively.

The experience of Dr. Hurst on silicon iron is of considerable interest, particularly as this material undergoes no major transformation in the temperature region where the creep strength is appreciable. It would be useful to know whether the cracking in silicon iron has the other well-known habits of hair-line cracks, *i.e.*, do the cracks occur in large numbers restricted to the centre of the section, or are they in the nature of gross cracks passing right through the section ?

Discussion on—

THE FLUIDITY OF STEEL*

by R. Jackson, D. Knowles, T. H. Middleham, and R. J. Sarjant

Mr. T. H. Middleham (Messrs. Hadfields, Ltd.) presented the paper entitled, "The Fluidity of Steel," by R. Jackson, D. Knowles, R. J. Sarjant, and himself. In doing so, he called attention to a few printing mistakes. On page 10, second column, the reference to Fig. 1 should be to Fig. 11. On page 14, the inscriptions to Figs. 21 and 22 had been reversed. On page 20, in Fig. 29, the time scale had been omitted. The time was, of course, in seconds.

Dr. **W. C. Newell** (British Iron and Steel Research Association, London): This subject of fluidity is one which is very well known to the practical foundryman, and he is well aware of its relationship with temperature. In fact, he speaks familiarly of fluidity as "life," and associates it very much with "heat," which we call temperature. But it is only very recently, in spite of the large amount of practical work done on fluidity, that accurate temperature measurements have been made possible by means of the quick-immersion pyrometer, and the work which we are now considering is one of the first to take advantage of the new method available for the reliable measurement of temperature. I think that the authors are to be congratulated on the volume of work which they have done, on its quality, and on the systematic care with which they have taken their temperatures and made careful comparisons of the temperature by the two standard methods, the optical and the quick immersion. The amount of work involved is, as will be seen from the paper, immense, and the conclusions are most valuable.

I intend to refer briefly to some of the salient conclusions. They are indicated in the paper, but to my mind they are not as clearly stated as they could be, and by a re-statement of the conclusions I think that I can draw out several points of value.

One of the outstanding conclusions, which will be a great help to us in future work on the subject of fluidity, is the authors' clear recommendation of the Taylor, Rominski and Briggs Spiral fluidity test, and this in spite of the fact that they started this investigation under the impression that the simpler Ruff test would suit their needs. In spite of that initial misconception, the authors have come to the conclusion that they prefer the Taylor-Rominski-Briggs Spiral test; they have stated their preference clearly, and they have given figures for the standard deviations of the two methods of examination which confirm and justify that conclusion.

The second point is the valuable information given on the correlation of the optical pyrometry readings with those obtained by the quick-immersion pyrometer. There is much valuable information in the early part of the paper on the relative readings for different types of steel, both acid and basic, and in particular the discrepancies between the acid and basic steels are most interesting, apart from any fluidity considerations.

The third point is the close correlation between the fluidity and the optical pyrometry reading as compared with the correlation between the fluidity and the quick-immersion reading, or, if I may so call it, the true temperature reading. This is demonstrated in many ways. It will be seen from the graphs that the optical points are as closely spaced to the lines drawn as for the quick-immersion points. We know that the errors on the quick-immersion pyrometer are less, and the standard deviations are known to be less, so that we should have expected a better-defined line to be obtained of necessity from the quick-immersion readings, but that is not so; the correlation with the optical readings is closer than with the immersion readings. Thus fluidity follows a simpler correlation with the apparent temperature rather than with the true temperature.

We are well aware that acid steel is more fluid, or so we usually think, and by the optical pyrometer that observation is confirmed; it appears from the optical-pyrometer readings that the acid steel is the more fluid; but by comparison of the immersion readings against the fluidity it is seen that there is scarcely any difference, and if anything the tendency is the other way, though it is a small effect and probably within the experimental error. Comparing true temperatures against fluidity, particularly by the Taylor-Rominski-Briggs Spiral, the correlation of fluidity and true temperature is not only very close but does not differentiate between acid or basic steel. That is a very important conclusion, because as scientists we hate to be tied down to something indefinable, and the mere expression of "acid" or "basic" steel, without some understanding of it in terms of composition or something else, is annoying. Thus it is gratifying that this work has shown that on a true temperature basis there is a close correlation with fluidity independent of the type of furnace lining employed.

A point which is dealt with earlier in the paper, and which really seems to be the provocative cause of this work having been done, is the American comment on the earlier work. The substance of it is that the Americans criticized the direction of the curve indicated by Sarjant and Middleham in their earlier work. The tendency from that earlier work was to give a curve of the form A (Fig. A). The Americans said that that was wrong, and that the curve should have the form B. I am bound to admit that the Americans seem to me to be right there. The general effect of a given change in temperature upon properties decreases the higher the temperature, or, to put it the other way round, the effect of a change in temperature must be considered in relation to the absolute temperature that is under consideration. Another way of putting it on a thermodynamic basis is to say that in considering the alteration in properties in relation to a change in temperature it is better to judge that change on a logarithmic basis and take a differential of the logarithm of the temperature rather than of the absolute temperature itself. This reasoning indicates that there should be a flattening off of the fluidity with rise in temperature. One would not expect the fluidity to increase its rate of increase with rise in temperature over any large range, assuming no discontinuities of phase change.

The work which is described in this paper tends rather to fall into line with the American idea that the curve should be of the type B, but I can see from a careful examination of the results the reason for the curve going apparently in the other direction, as shown by A. There is in the paper the exception, in steel F. 319, which shows a curve of a double type, with a kink in it. But the exception, as usual, proves or demonstrates or

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Sept., pp. 1–21.

exhibits the rule, and if we examine the other results we find that there tend to be rather more points in the higher fluidity range than in the lower fluidity range, but there seems to be a gap in the points at about the middle of the curves, so there is a possibility that there may be a kink as revealed for steel F. 319.

What I am going to suggest, however, is that in reality we are considering the effect of two distinct factors upon the fluidity. Taking the kinked curve shown by steel F. 319 as the true curve for all of the steels, it is easy to draw a curve which bends the other way, as shown by the dotted line (Fig. B). I venture to suggest that this is the probable explanation for the fact that in the earlier paper the curve was put round the wrong way. The point is well demonstrated if you consider Figs. 15–18, which show the kink to which I refer. It is a striking fact, as has been pointed out by Mr. Middleham, that this kink for steel F. 319 is not shown when the optical pyrometer reading is compared with the fluidity. Once again we come to the fact that the apparent temperature as determined visually or optically is more closely in line with the fluidity than the true temperature. Thus the foundryman is right : what he thinks is the fluidity, the life of the steel, as visually observed, does fall into line with the apparent temperature rather than the true temperature.

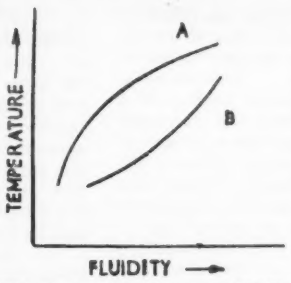


Fig. A—(A) Sarjant and Middleham's and (B) the Americans' types of curve

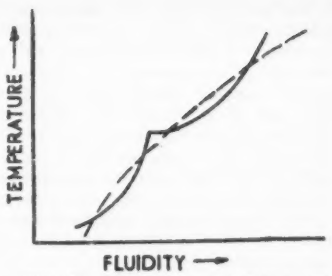


Fig. B—Possible variations of fluidity curve for Steel F.319

Now we come to the mechanism of fluidity, and I think that this is where I would be rather more rash than the authors. They have suggested that surface films play a part. This has been mooted many times before, and personally I feel convinced that the surface film is the determining factor as far as fluidity is concerned. We know, from such evidence as we have, that the internal viscosity of steel is very low, and it seems that the factor which determines fluidity is a surface property, the surface tension of the steel itself, or more probably the surface tension of any oxide or slag film which is formed on the steel.

The evidence of analogy is considerable. Let us look in another direction and think of light-alloy foundry experience. There the oxide film formed on aluminium is clearly the controlling factor in the fluidity of the casting of light alloys. The accepted technique of light-alloy foundries is to cast the metal through what appears to be a pipe of oxide, and foundry practice in the light-alloy field involves that principle of steady pouring through a naturally formed tube of oxide which forms round the pouring stream. Also, in light alloys, metal which is sluggish can be changed in its character quite easily by the addition of other elements which apparently change its flux-forming possibilities. We know, for example, that in the production of aluminium the virgin metal as it comes from the furnace is very much more fluid in appearance than the metal which has been handled, and that can be shown to be due to the presence of surface fluxing material, in that case cryolite.

On this basis the fluidity of steel is largely determined by the formation on its surface of oxide or silicate, and the composition of this oxide or silicate which is formed on molten steel is determined by the composition of the steel. Steel forms a skin round it as it runs, and the composition and the properties of that skin will be determined by the composition of the steel : but it is not the major components of the steel which are of importance but rather the minor components—especially silicon and manganese. It is a striking fact that steel F. 319, which demonstrates the kink, is abnormally low in silicon. I suggest, therefore, that this low silicon content controls the silica content of the slag which is formed on the metal as its surface is run or a fresh surface is formed.

We know how this same problem arises in steel manufacture with dazed steel. The problem of dazed steel is closely analogous with the fluidity of steel in the foundry, and the case of dazed steel is again associated with minor changes in composition—usually dazed steel is associated with acid steel practice where the silicon has tended to rise higher than usual. We know that the melting point of these chemical systems varies immensely and that we can go into high melting-point ranges with high silicon as well as with low silicon, so that it does not go against the general reasoning that the minor-constituent composition of the steel itself is the determining factor.

On that basis we have to consider that at the lower temperature range there forms round it a skin which may have adhesive wetting properties to the steel, so that it keeps a film covering. Its surface tension is less than its adhesion to the steel surface. That applies up to the lower temperature range below the kink in the curve, and after that there is a point where the relationship of surface tension or melting point changes, and with the oxide running off there is a fresh steel surface formed readily. I put that forward as a working basis for considering this subject to be the mechanism of fluidity in steel.

Certainly this suggestion is a useful and profitable basis of reasoning, because it gives us something to work upon, and it enables us to look for clues as far as the variation in fluidity with composition is concerned. In future work we must watch the minor components of the steel, such as the silicon and manganese.

Those are the main points that I want to raise with the exception of the old problem of the term " fluidity." I think that this work has demonstrated once again that " fluidity " is a misnomer. The only other term which I can think of which fits the facts is " foundability," but that lends itself to puns rather too easily. Finally, I should like to thank the authors very much for this stimulating paper. They have made a signal success of their clear comparison of the important properties of the temperature/fluidity relationship.

The **President** (Dr. C. H. Desch, F.R.S.) : I remember giving a paper to the British Institute of Foundrymen some years ago, and " castability " seemed to be the term in general use amongst them. I think that there is an objection to the word " fluidity " because it has a definite physical meaning, the reciprocal of the viscosity, whereas it is actually a combination of properties which we are discussing under the name of " fluidity."

Mr. **J. E. Worthington** (British Iron and Steel Research Association, Sheffield) : Dr. Newell said most of what I

should have liked to say about the surface film effect on fluidity, but there is one point which I should like to mention. I wonder whether it will be possible to gain a measure of the strength of the surface films—not the surface tension alone, but the combined surface film due also to the oxide-skin effects which may increase the true surface tension to about three times its normal value—from a measure of the difference between the optical and the immersion temperatures ? There was a paper published in the April, 1947 issue of the *Journal of The Iron and Steel Institute** which gave some idea of the effects of oxide and other surface films on the emissivity of a steel.

It should be pointed out that the American investigators used a green-sand mould in their investigations, claiming that they could reproduce moulds to a finer degree of accuracy—as regards moisture content—when using a definite percentage of water (3%) than when using a dry-sand mould, which might slowly absorb water. I believe that the use of a green-sand mould might have eliminated the flashing which the authors obtained in some of their moulds.

Would it not also have been advisable to have cast the Ruff bar and the Spiral in the same mould, thus casting both test-pieces using the controlled head possible with the Taylor, Rominski and Briggs Spiral ?

Finally, I notice that the error attributed in this paper to the Americans' temperature readings is "at least 25° C." In some cases, however, there is a discrepancy of at least 75° C. in the results given, so it seems possible that there is some other factor influencing this difference. Is this perhaps due to variations in the pouring speed ?

Mr. **N. H. Bacon** (Steel, Peech and Tozer, Sheffield) : This seems to me to be a most valuable piece of work, and of particular value is the fact which has been established that at the true temperatures acid and basic steel are of equal fluidity. That came as a great surprise to me, because, like others connected with melting shops, I felt certain that acid steel was more fluid than basic. Apparently the authors have given the correct explanation, that they appear to be at the same temperature when actually there is a marked difference.

There is one question which I should like to ask in connection with the curious curve obtained with the steels of low silicon. I should not have expected steels of that analysis (0·28% of carbon and 0·61% of manganese) to be really fully killed having a content of 0·07% silicon, and I wonder whether any tests were made to ensure that the steel was actually fully killed and that there was no gas reaction ?

The other point which I should like to mention is the difference in fluidity or castability between these steels. I wonder whether that difference in the castability at given temperatures is due to the different degrees of superheat ? For example, steel F. 319, with 0·28% of carbon, a plain carbon steel with 0·07% of silicon, will have a considerably higher freezing point than steel F. 295, with 1·05% of silicon and 1·31% of manganese. I wonder whether the authors have determined, or if not, would think it worth while to determine, the freezing point theoretically and then see whether for a given degree of superheat the fluidities were approximately the same in all cases ?

Mr. **T. H. Middleham** : Dr. Newell has given a very good exposition of the paper, and we are grateful to him and also to Mr. Worthington and Mr. Bacon for their contributions. It is not possible, in the limited time available, to reply adequately to all the points that have been raised, and, rather than deal now with a selection of the questions, I think that the whole of the reply can better be done in writing.

AUTHORS' REPLY TO DISCUSSION

With regard to Dr. Newell's interesting discussion, we are grateful for the careful study which he has given to the paper. We have been under no misconceptions as to the relative values of the two types of fluidity test, namely, that initially suggested by Ruff, and that known as the Spiral. The separate approach to the two problems was prompted by the following considerations. Spiral tests were known before the Ruff test was suggested, but the relative simplicity of the Ruff test was attractive, and its examination was undertaken as a subject which at the time engaged the attention of the Steel Castings Research Committee. The later work with the Spiral test used by Taylor, Rominski and Briggs was prompted by the fact that considerable discrepancy existed between the results of the earlier work of the two authors (R. J. S. and T. H. M.) and those of the American authors. The investigation served primarily to ascertain the cause of the discrepancies. The relative merits of a Ruff test as against a Spiral test was quite a secondary matter. The suitability of the methods for fluidity measurement under foundry conditions is determined largely by workshop considerations, and it had been realized by the authors, prior to the conduct of the tests reported, that the Ruff test, as a practical foundry method, had certain disabilities. If suitable casting conditions could be applied in the workshop the Ruff test was of some value, but its universal application was impracticable. The main issue was not, therefore, whether the Spiral was a better form of test than the Ruff, but whether trials conducted under normal conditions in two foundries with different techniques of temperature measurement would give the same results.

Dr. Newell discusses afresh the point in regard to the unexpected form which the curves of Sarjant and Middleham took in the earlier experiments. This unexpected character was recognized by the authors at the time, and the work, therefore, was carefully repeated in those experiments. Since the same form of curve was obtained the authors faithfully recorded their observations in spite of their expectation that the results would be criticized. The cause of the form of that curve has not yet been revealed.

We agree that the form of curve published by the Americans seems more reasonable, and it was the lack of agreement between our earlier results, possibly associated with some specific experimental conditions, or difficulties of technique using the 18-lb. furnace which led to the use of the 2-cwt. furnace. This was a matter purely of experiment, and not of theoretical claims.

Dr. Newell's suggestion as to the possible cause of the shape of the earlier curve is ingenious, but not in line with the experimental facts then observed. The kink in the curve for F. 319 was quite pronounced, and no semblance of this feature appeared in the curves for any of the other casts, in each of which there was an adequacy of observations.

The effect may be associated with the formation of an oxide skin, the influence of which upon emissivity has been noticed before.* It would be expected, however, that such an influence would have been reflected in the curves of fluidity based on optical temperatures, but no such indication results. Observations on the fall of temperature with time showed an increase in the rate of true temperature drop in the region of 1570° C., with no appreciable change in the rate of fall of the apparent temperature. Dr. Newell's discussion of the mechanism of fluidity involving the formation of a skin of oxide is

* D. Knowles and R. J. Sarjant, *Journal of The Iron and Steel Institute*, 1947, vol. 155, April, pp. 577–592.

perhaps more germane to a rational explanation of the results obtained by Sarjant and Middleham. The results were carried out on a small scale, and a thin rod of steel is cast in the Ruff test. If films of oxide can influence the fluidity so materially, then the formation of such films could well be expected to influence the apparent fluidity as observed by the test.

It cannot, however, yet be said that the surface film is the controlling factor in fluidity. It has a considerable influence, as is shown by the skin-bounded ends of spirals cast in manganese steel, but we would hesitate to say it is the only factor.

In reply to Mr. Worthington, the closer agreement between temperature and fluidity when based on optical than on true temperatures indicates some factor which influences apparent temperature and fluidity but not true temperature. Knowles and Sarjant have shown how emissivity is affected by surface films, which can also affect fluidity. It would, therefore, appear that a comparison of true and apparent temperatures with fluidity could give some measure of the film, though not necessarily its strength.

With regard to the type of sand used for the moulds, whether green or dry, the original American work indicated that this had no influence on the results, but in a later publication* green sand was recommended. From the practical point of view, and under foundry conditions, the greater strength of the dry sand mould is an advantage. The possibility of moisture absorption after drying was eliminated in our tests by not allowing the dry sand moulds to stand between drying and casting.

The Ruff and Spiral moulds were deliberately used as two types of test mould, and it was considered that nothing would be gained by incorporating them in the same mould.

The error which we attributed to the Americans' temperature measurements was "at least 25° C.," and in cases in which not only temperature but the condition of the steel in regard to the presence of the all-important oxide-film are operative factors, it is unwise to dogmatize upon the magnitude of the real differences of temperature in the two series of experiments. The authors felt that a difference of 25° C. could be justified on the evidence obtained, but the whole of the difference might well have included other operational factors.

The controlled head in the T.R.B. spiral is not altogether positive, and permits considerable variation in pouring speed. Provided that the total time of pouring was under 4 sec., it was found that the actual speed was unimportant, but slower pouring gave erratic results. Both sets of work are apparently consistent in themselves, which would not have been the case had the pouring speed been outside the permitted range.

In reply to Mr. Bacon, the accepted view of the superior fluidity of acid steel over basic is in some measure attributable to factors encountered in normal practice other than the properties inherent in the molten steel. Differences in the thermal properties of the ladle linings and slags will affect the rate of temperature drop in the ladle, and so influence the fluidity when casting.

The low-silicon steel referred to was, as Mr. Bacon surmises, not fully killed, and some of the test casts were actually rising in the heads. There was, however, no apparent shift in the position of the temperature/fluidity curve as the steel passed from killed to rising.

* K. L. Clark, *Proceedings of the Institute of British Foundrymen*, 1945/46, vol. 39, pp. A52–63.

Discussion on—

THE MECHANISM OF CARBON REMOVAL BY OXIDATION FROM THE BATH IN THE OPEN-HEARTH FURNACE* *by the late A. H. Jay*

Mr. **G. E. Speight** presented the paper by the late Dr. **A. H. Jay** (The United Steel Companies, Ltd.) which had been published in the *Journal*, 1947, vol. 157, Oct., p. 167. In doing so, he said : It is a very sad duty that I am called upon to perform, but it is one in which I take great pride. I am sure that Dr. Jay would have enjoyed being here today to give his paper and to answer, in his usual quiet way, the many points which will be raised on its subject matter. As is well known, he had a very real interest in the fundamentals of the steelmaking processes. He was essentially an original thinker, and was often most unconventional in his approach to problems and in their solution. He always contrived to explain the steelmaking processes on the basis of simple conceptions. His 1945 paper on the phosphorus reactions showed all these characteristics.

The present paper is in somewhat similar vein. The views expressed on the mechanism of the carbon reaction are interesting, to say the least, but they are definitely provocative, and I should make it clear that although he freely discussed these problems with his colleagues—and we had many heated discussions—the views given in the paper are entirely his own. The paper is what might be termed an armchair research, and gives the results of concentrated thought on experimental data obtained by previous investigators. Although the conclusions might be considered to be far from proved, it was Dr. Jay's wish that they should be published for the purpose of stimulating further thought and discussion on the mechanism of this reaction, and a vigorous and frank discussion would be, perhaps, the best compliment that we could pay to his memory.

The paper deals with two features of the open-hearth process. The first is the increase in silicon and manganese which occurs in the acid process, whilst the elimination of carbon apparently proceeds, though at a somewhat reduced rate, and the second is the relative importance of the carbon concentration and the oxygen concentration on the rate of carbon removal. It is well known that there have been many papers dealing with the latter problem and that many of these, instead of making the position clearer, have added to the uncertainties that already exist. The carbon–oxygen product is generally held to have a dominant effect on the rate of carbon removal, although the precise nature of the relationship is very frequently clouded by other factors, such as the degree of agitation of the bath, slag viscosity, rate of CO bubble formation, the surface condition of the hearth, and, last but not least, the variation of the equilibrium constant itself.

Several American workers have stated their belief that the carbon reaction is largely determined by the

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Oct., pp. 167–172.

concentration of FeO rather than by the product of FeO × C. Typical of the complexity that has crept into the subject, however, is one very beautiful statement that I have seen, which is as follows : " The equilibrium constant for the FeO + C = Fe + CO reaction is (concentration of FeO) × (concentration of C) ÷ (concentration of CO), wherein the concentration of CO varies with the concentration of C in such a way that compensates for the inconstancy of the product FeO × C." I do not know what that really means !

Dr. Jay considered that the two features to which I have already referred—the increase of silicon and the increase of manganese being one, and the rate of carbon removal being the other—were fundamentally related, and this paper sets out in a simple manner the trend of his thoughts. The paper is very short, and after the introduction it seems to fall naturally into three parts. In the first part, it is shown that the rate of carbon removal is related directly to the degree of oxidation. Dr. Jay took the view that an increase in silicon and manganese in the acid open-hearth process can indicate only a decrease in the content of reactive oxygen. The contents of silicon and manganese, therefore, should be a measure of the state of oxidation. By a simple application of mass laws to typical data from an acid heat, the ratio of the degrees of oxidation at two periods in the heat when the manganese and silicon are constant (at the end of the ore boil and at the end of the limestone boil, in this example) is shown to be similar to the ratio of the observed rates of carbon removal at the same periods, when the carbon contents are widely different, being 1·1% and 0·33%, respectively. This rather close correlation between the rate of carbon removal and the degree of oxidation, particularly at such widely different carbon contents, would indicate rather strongly that the controlling factor in the rate of carbon removal is the state of oxidation, *i.e.*, the concentration of reactive oxygen, rather than the product of FeO × C.

The next part of the paper deals with a suggested mechanism of the carbon reaction, in which the dominant rôle of oxygen is shown in rather strong relief. Dr. Jay considered that the primary molecular bubble of carbon monoxide would grow by a two-stage reaction with oxygen and with carbon alternately. Since the number of carbon atoms is considerably greater than the number of oxygen atoms, except at very low carbon contents, the reaction of the CO bubble with oxygen to CO_2 would be much slower than the subsequent carbon reaction to CO. It could be said, therefore, that the concentration of oxygen atoms would thus govern the ultimate rate of carbon removal, although obviously the carbon would eventually be eliminated mainly as CO.

In the last part of the paper the theory has been tested by resort to mathematical physics. The calculation gives an interesting result. It shows that on the surface of the primary CO bubble there are 3300 iron atoms. When there are one or more oxygen atoms on this surface, the reaction $CO + O \rightarrow CO_2$ can presumably proceed, the CO_2 bubble being *at once* reduced by carbon to yield a larger CO bubble, and so on. One oxygen atom in 3300 iron atoms gives a weight oxygen concentration of 0·009%. That value, then, could be regarded as the minimum excess oxygen content over the equilibrium value which will be necessary in order to obtain steady removal of carbon, and it agrees remarkably well with the very detailed results obtained by Larsen, who showed that for steady conditions of boil an excess oxygen content over the equilibrium of 0·009% is needed.

Finally, I suggest that although there is much in this paper which requires to be proved, and there are many objections to the treatment which has been given to the subject, there still remains a simple conception of the elimination of carbon which is well worthy of consideration.

Dr. **J. H. Whiteley** (Consett Iron Co., Ltd., Consett, Co. Durham) : A careful study of this very interesting paper led me to the conclusion that Dr. Jay had not taken sufficient account of several things which might affect the carbon reaction in the acid furnace. In the first place, there was the fact, now fairly well established, that silica can be reduced to a certain extent by iron itself, the FeO so formed passing into the slag and the silicon into the metal. Now that reaction will be most likely to occur towards the end of the boil, especially when limestone has been used, for the iron oxide content of the slag should be then at a minimum and the temperature of the metal at or near a maximum. Consequently, a part of the silicon present in the steel at stage *b* of the cast Dr. Jay has cited may have arisen in that way and, as a result, the ratio O_a/O_b derived from the silicon contents of the bath at the two respective stages *a* and *b* should be greater than the same ratio calculated from the manganese contents. That is precisely what Dr. Jay has found. In Table II he gives a ratio of 2·4 for the silicon as against 2·0 for the manganese, so that this consideration tends to support his argument.

The reverse is the case, however, with the next thing I would mention, which is that carbon can be eliminated by direct action at the slag/metal interface, so that even if the solubility of the oxygen in the metal was infinitesimal a steady boil would still be possible. Moreover, as Dr. Hallimond and I pointed out many years ago,* up to 5% by weight of the metal in the form of droplets is continually passing in and out of the slag during the boiling period, and we found that in so doing their carbon content is considerably reduced. That mode of carbon removal has recently been confirmed by another worker but, unfortunately, I have not kept the reference. It may be contended that a direct action between the carbon in the metal and the FeO in the slag at the interface implies at least some slight solubility of the FeO in the metal, and I would reply that there may equally well be a similar solubility of the carbon in the slag. That a direct reaction between the slag and metal does occur there can, I think, be little doubt. It will, of course, proceed at the greatest rate during the early stages of the boil when both the carbon in the bath and the FeO in the slag are relatively high ; in fact the difference Dr. Jay found between the ratio of carbon removal at the *a* and *b* periods (Table II) may readily be explained in that way. His conclusion from this difference that the rate of carbon elimination is controlled by the amount of oxygen dissolved in the metal thus appears to be a very dubious one indeed. In connection with the slag/metal reaction, I should also mention that sulphur in the metal may aid decarburization. It is, of course, well known that FeO and FeS are mutually soluble and if, as seems likely, FeS particles are continually passing in and out of the slag they will carry with them some FeO in solution and so increase the rate of carbon oxidation. To what extent this effect may occur I cannot say, but I should mention that acid slags have an appreciable sulphur content, and I have noticed that high-sulphur acid charges have a very free boil.

Lastly, I would refer to Dr. Jay's supposition that carbon dioxide plays a part in the carbon removal. He

* *Journal of The Iron and Steel Institute*, 1919, No. I. p. 228.

postulates a gas bubble consisting of one molecule of carbon monoxide and calculates that there will be 3300 iron atoms in the unit atomic layer on the surface of this primary molecular gas bubble. He then states that if one atom or more of oxygen is present in the layer, carbon dioxide is likely to be formed from the carbon monoxide. But he seems to disregard the fact that many atoms of carbon will be in the close vicinity of the oxygen atom, especially when the bath is high in carbon, so that in all probability the oxygen will combine with a carbon atom rather than with the carbon monoxide.

Dr. **F. D. Richardson** (British Iron and Steel Research Association, London) : Before speaking on the subject of Dr. Jay's paper, I should like very much to endorse the preliminary remarks of Mr. Speight, and to say on my own behalf how much I regret that Dr. Jay is not still with us to be able to take the lead in this discussion. I make my criticism, however, with the feeling that he himself would have welcomed an animated discussion and as strong criticism as possible.

In dealing with the paper as it stands, I should first like to refer to Table I, because I think that merely on the basis of the figures in Table I it is possible to infer almost anything one likes. For instance, if we take the trouble to plot the relative rates of carbon removal, at the different times at which the analyses were taken, against the relative oxygen contents or degrees of oxidation as calculated in the paper, we get a set of points as shown by the circles in Fig. A. The 1 : 1 relationship is represented by the straight line.

For complete correlation the points should lie along this line, but actually they are as plotted. We get almost as good a correlation, however, if we plot the relative rates against the relative percentages of carbon present, as shown by the crosses. If we were convinced that both the carbon and the oxygen concentrations determined the rate it might be claimed that it depended on the square root of the product of these two concentrations. In fact, from the few figures in the paper it is impossible to make any significant inference.

My next point concerns this picture of a monomolecular carbon monoxide gas bubble. The size of that bubble, as worked out in the paper, is about 38×10^{-8} cm. For a bubble of that size to exist, the excess pressure inside it, owing to the surface tension of the iron, would have to be very great. On the basis of the experimental figure for the surface tension of iron at these temperatures, it is theoretically of the order of 5000 atm. This means, of course, that such a bubble could not exist. You may say "If it is 5000 atm. we shall have to have it very much smaller," but the smaller you make it the greater the excess pressure. You can go to 10,000, 100,000, or anything you like, but finally you will be faced with the fact that you just cannot have a monomolecular gas bubble of CO in your liquid iron. A single molecule in the liquid is, of course, rubbing shoulders with the surrounding iron atoms.

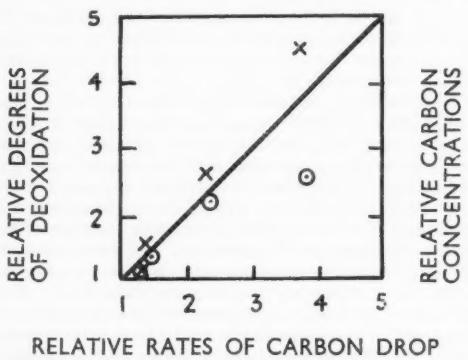


Fig A—Plot of results in Table I

My third point is that, even if we did work to the basis of this theory, we would not be led to a critical figure for the FeO concentration at which the reaction could proceed. At the calculated figure we would need, as Dr. Jay has said, 0·009% of oxygen there to have one oxygen atom on the surface of the bubble ; but that will be only one oxygen atom *on the average*, and if you care to reduce the oxygen concentration to half that amount it follows statistically, not that the rate of reaction decreases very rapidly, but that it falls merely to half its previous value.

On three counts, therefore, I feel that this picture is not a satisfactory one. My criticisms do not, of course, invalidate any other theory or argument which contends that the rate of removal of carbon is dependent predominantly on the FeO concentration, but I would say that the experimental results which are quoted here do not in any way substantiate that view.

Mr. **H. O. Howson** (Blaenavon Co., Ltd.) : Before discussing this paper, I should like to express my appreciation of the late Dr. Jay. We shall miss him very much, and I wish that he were here to take part in the discussion. Any comments which I make on this paper are made with the full realization of Dr. Jay's previous work, and of the stimulating interest that this paper will create in this ever-present and intriguing problem of what is really happening in a furnace bath.

To some extent Dr. Whiteley commenced along the line I wish to follow, in referring to the fact that we have pellets of steel thrown up into the slag, but I would like to go a little further. It is my personal opinion that the pellets of metal are carried right through the slag and into the furnace atmosphere, and that primarily the oxidation of these pellets occurs in the furnace atmosphere. Under the conditions some of the carbon will be removed from the surface, but more particularly the effect is to form a film of FeO which, carried back into the metal, promotes the boil.

We come to the conclusion, therefore, that in the acid open-hearth process we have to a large extent the removal of carbon through actual oxidation by the furnace atmosphere. The various gases in the furnace atmosphere all play a part, and I think that we thus obtain a conception of the various acid processes which is valuable.

Primarily we have the acid Bessemer process, in which the air is directly in contact with the metal. Then there is the side-blown converter, in which the air stream strikes the surface of the metal to some extent. In the acid open-hearth we have a similar picture—the air is striking the metal, but the slag/metal reaction plays an increasing part. Finally, in the acid electric process there is a predominantly reducing atmosphere, and we encounter purely slag/metal reactions. Full account must be taken of this question of oxidation in the furnace atmosphere in considering the acid open-hearth furnace.

To return to particular points in the paper, I think that it is somewhat unfortunate that only one example of an acid furnace charge was taken. In all work of this description, I believe we benefit by taking a number of heats, and I would prefer to see this, particularly as we may observe by the figures given that this charge was somewhat exceptional for the acid open-hearth process. It was evidently a charge with a rather high proportion

of pig in it—I imagine 40·45% of pig—but the unusual part is that the residual silicon increases to 0·21% before any ferrosilicon or silicomanganese was added. I believe the majority of people connected with acid open-hearth processes will look on this as rather a high figure ; normally we do not get silicon much above 0·1%. If we take the formula given in the paper :

$$\frac{[O]_a}{[O]_b} = \sqrt{\frac{[Si]_b}{[Si]_a} \times \frac{(SiO_2)_a}{(SiO_2)_b}}$$

and calculate for a more normal type of charge, in which the residual silicon will probably be about 0·1% or, exceptionally, 0·2%, we shall have approximately the same concentration of silica in the slag, and I think we would get a rather different series of figures and results from those obtained by the author.

To return to the point introduced by Dr. Whiteley, the actual reduction of silica by iron, we know that this reaction can take place. Obviously something similar is happening in the blast-furnace, and it is also, I believe, fairly apparent that carbon may play a part in the reaction. It is quite a simple matter—it is done in the preparation of ferrosilicon—to reduce silica by carbon, and this is important. The iron occupies the greater bulk of the bath, but in the higher-carbon charges we have a reasonable amount of carbon there. As the carbon falls, the iron will be the predominant factor in the process, but we have to face the fact—and it is rather a perplexing one—that the acid open-hearth process is fundamentally oxidizing, and yet taking place in the same bath and at the same time there is a reducing action. We must assume that the reappearance of silicon in the bath after being almost entirely oxidized away is a reducing action. That is a peculiar, and in my view a fundamental, point in understanding the mechanism of the acid open-hearth process.

I would like to suggest a theory I have had in mind for a number of years, and that is that the silicon which reappears in the bath originates entirely from the furnace hearth. I am in a position to advance practical points to substantiate this, but am unable to do so in the short time available. I do not think that there is anything unreasonable in the supposition. The major factor in support is that the hearth is definitely a more siliceous material than the slag. A newly fettled hearth may have a silica content of 85%, and even in a worn hearth it is rare for the silica content to be below 80%. In addition, there is a greater area of hearth exposed to the metal surface than in the case of the slag. I advanced these points at the meeting on acid converter practice and shall not repeat them, but I believe if this is accepted—and I see no reason why it should not be—it will rather invalidate many of Dr. Jay's conclusions in assessing the degree of oxidation of the bath by the silicon present.

I regret that in the paper no mention is made of temperature. I think that in all furnace reactions temperature plays a very important part, and this applies more particularly in the acid open-hearth process, in which temperature is the determining factor. I suggest that the conditions under which silica is decomposed into silicon and oxygen are largely determined by temperature and are quite distinct from the degree of oxidation of the metal or of the FeO content of the slag. This is not strictly connected with the paper, but I advance this theory, and I think it is a just criticism of the paper that if these reactions can take place it is useless to try to assess the degree of oxidation through the silicon content.

Otherwise there is a great deal of value in the paper, but my main thought is that it does suggest a new viewpoint and a new outline of the subject, which I think is valuable, because in our papers and discussions we are apt to regard the furnace bath as though it operated in purely laboratory conditions, with the bulk of the metal covered by slag and all the reactions taking place as they occur in a small crucible under laboratory conditions. The attitude that Dr. Jay has adopted and the suggestion that we should have regard to a wider aspect are very valuable. It is a great tribute to Dr. Jay that he has made these suggestions.

Dr. **C. Sykes,** F.R.S. (Brown-Firth Research Laboratories, Sheffield) : It has occurred to me that most of the speakers in this discussion have been concerned with what happens after the boil starts. I think that, at any rate as far as the oxygen limit is concerned, Dr. Jay was concerned with the conditions necessary to start the boil. I entirely agree with Dr. Richardson's remarks with regard to the fact that the bubble postulated by the author is not likely to occur physically, it being far too small, but I think we ought to turn the problem round the other way. There will undoubtedly be a minimum size of bubble which can form in the bath, and presumably the general relationships governing that size of bubble will be similar to those that decide whether we get bubbles in a test-tube when we put it over a Bunsen burner, and so on. It seems to me that it would be worth while making a calculation to see whether this minimum amount of oxygen, 0·009%, is necessary in order to enable one to form the minimum size of bubble. In any event it is clear that one of Dr. Jay's points, that a minimum amount of oxygen is necessary to start the boil, must be correct.

Mr. **A. G. Hock** (Workington Iron and Steel Co., Ltd., Workington, Cumberland) : I am taking part in the discussion chiefly because I wish to pay my tribute to the memory of Dr. Jay and to record the great value of his work to his colleagues and to the Company with which he was associated.

It is in no spirit of criticism that I submit that Dr. Jay would have faced the possibility that his result may not be correct. Such is the position of a pioneer who has attempted to do what has not been done before. It seems trite to assume that sufficient carbon and oxygen atoms must be present before a bubble of gas can be evolved, and to recall that such evolution is helped by the presence of another phase and by mechanical effects such as stirring.

Previous speakers have mentioned the large pressures caused by surface tension in small bubbles, and the effect of this on the calculations in section V. If it be right to regard a " molecular bubble " as still in solution, then Dr. Jay offers an alternative, *viz.*, to regard the elementary volume as the sphere of influence of the molecule under thermal agitation. However, the bubble must eventually come out of the bath and this point has been covered by Dr. Sykes.

It is difficult to see how CO_2 can readily be produced in liquid steel at 1600° C., say, by the reduction of the oxygen-bearing bath by CO, unless this reaction takes place with a phase carrying a higher oxide than FeO (such as slag). Moreover, the unlikely supposition that all, or nearly all, the CO_2 formed would be reduced by carbon only has to be made in order to increase at this stage the number of CO molecules. It seems probable that this problem is connected with the rate of access of a suitable oxygen-bearing phase to the steel bath. Such a rate will control the whole process if it is the slowest of a chain, and it is interesting to recall that carbon can be removed by the intermediary of oxide-bearing slags at rates of the order of ½ %/min. in pneumatic processes.

Unfortunately, this line of attack appears to suffer, like the others, from a lack of data which arises from the difficulties which beset experiments on the exact states of oxygen in a steel bath.

In spite of disagreement with the process of calculation as it now stands, it is interesting to note the good agreement with results published by Larsen. The novel way in which Dr. Jay has looked at this problem is very refreshing and deserves our highest praise.

Dr. **F. D. Richardson** (British Iron and Steel Research Association, London): It is difficult to give a direct answer to Dr. Sykes' question about the minimum size of bubble which can exist in the system. We can calculate, of course, the sizes and pressures for spherical bubbles existing in our liquid iron. It is certain, however, that the smallest bubbles will exist at irregularities, or at tiny gas pockets, at the interfaces between the liquid iron and the solid hearth, or suspended solids. Soda-water provides a well known example of this effect.

A bubble will be able to form at such an irregularity because, although minute, it will have a favourable shape. The radius of curvature at the gas/metal interface and hence the excess pressure within the bubble will be enormously less than for a similar quantity of gas enclosed in a spherical bubble. A pocket started in this way, or a previously existing pocket, will grow by carbon monoxide diffusing into it from the liquid metal, and by carbon and oxygen reacting in its vicinity to give carbon monoxide gas. The bubble will continue to grow until the radius of curvature at the gas/metal interface, and hence the internal carbon monoxide pressure, is in equilibrium with the local concentrations of dissolved carbon and oxygen. As is well understood from the maximum-bubble-pressure method of measuring surface tension, this pressure will be a maximum when the gas/metal interface is hemispherical. If the dimensions of the irregularity are such that the equilibrium bubble pressure is reached *before* the interface becomes hemispherical, growth will cease and no free bubbles will arise from this source. The degree by which the [C] × [O] product exceeds the equilibrium value for a CO pressure of 1 atm. plus the appropriate ferrostatic head will determine the radius of this hemisphere and hence the particular sites at which bubbles can develop fully. For an excess of 0·04% of FeO, as suggested by Fig. 3, and a carbon content of 0·5%, this radius is $7{\cdot}3 \times 10^{-4}$ cm. at 1 atm. external pressure and $8{\cdot}2 \times 10^{-4}$ cm. under 16 in. of iron.

If the conditions at any particular site are suitable for continued growth, the bubble will finally detach itself, leaving behind a small pocket of gas, from which a new bubble will be able to build up. The process can thus continue, until the [C] × [O] product is so reduced that the bubble can never become hemispherical. The detached bubble will grow as it rises owing to the reduction in the ferrostatic head and further entry of carbon monoxide into the bubble itself.

If, by some accident, such as a local swirl, a bubble smaller than the critical size were detached from the bottom, it would lose carbon monoxide to the bath and might be completely re-absorbed before reaching the surface. The smallest *stable* spherical bubble has, of course, a radius as calculated above, and in the second example would contain $2{\cdot}25 \times 10^9$ CO molecules.

There is one other possible source of bubbles which has been mentioned in the literature but of which, so far as I know, there is no conclusive evidence at the present time. It is claimed that if vortices exist in the bath the pressure at the centres of these vortices may be reduced sufficiently for a bubble to start forming and, if conditions are right, for it to grow rather than to collapse. That is, of course, a problem for physicists to deal with, and it is a possibility which I think is worth exploring more fully.

REPLY TO DISCUSSION

Mr. **G. E. Speight** wrote: I should like very much to thank all those who have taken part in the discussion, which is clearly indicative of the interest this paper has aroused. Had Dr. Jay been present he in his turn would have been stimulated by the very thoughtful and detailed considerations that have been brought forward.

There are several points in the discussion to which further comment might be made. Most of the contributors have made some reference to the "primary molecular bubble" of carbon monoxide. The difficulties of recognizing this as a separate physical entity are acknowledged. It must be remembered, however, that Dr. Jay's purpose was to show that under steady conditions of boil the rate of carbon removal was related more directly to the degree of oxidation than to the product of carbon and oxygen. He went a little too far, perhaps, in this direction, as it seems to me that the rate of carbon removal will depend also to some extent on the carbon content; in other words, at a given oxygen level the rate of carbon removal will doubtless be greater, though not necessarily in direct proportion, at the higher carbon level. It is impossible to state whether Dr. Jay recognized this secondary factor, but the fact remains he was convinced that the degree of oxidation was the primary factor, and to provide a simple, yet reasonable theory he introduced the conception of the "primary molecular bubble" which grows by successive reactions with oxygen and carbon until its separate existence and removal from the liquid becomes possible. Of the two growth reactions, that with oxygen was deemed to be the slower on account of the lower relative concentration of oxygen; it should control, therefore, the overall rate of bubble growth. Dr. Jay did not postulate the separate existence of the primary gas bubble, as a careful re-reading of the relevant passage in section IV will confirm. He visualized a condition where CO molecules were formed but were still contained within the liquid. Mr. Hock has perhaps given a more precise definition of this supposed condition, as being the "sphere of influence" of the elementary volume under thermal agitation.

Dr. Sykes goes directly to the point in asking what is the maximum size of bubble that can have separate existence, and I cannot improve upon Dr. Richardson's excellent reply to this question. But as Dr. Sykes points out, Dr. Jay was concerned with the conditions necessary to promote the appearance of the physical bubble, so that we are left with the thought as to what is the condition of the $2{\cdot}25 \times 10^9$ carbon monoxide molecules before they make their appearance as the minimum physical gas bubble. It is surely not impossible to visualize the gradual growth from a "molecular gas bubble" by a process similar to that outlined by Dr. Jay.

Dr. Whiteley and Mr. Howson make reference to several features more directly connected with the practical aspects of carbon elimination and with the return of silicon to the metal. A certain amount of direct elimination of carbon by the flame reaction on the iron pellets undoubtedly occurs; in fact many investigators have put forward evidence to cover this point, but it is surely not disputed that the major reaction in carbon elimination takes place between carbon and oxygen within the bath. It seems likely, therefore, that in addition to such direct carbon elimination that there may be between gas and metal, a more important function of the flame reaction is to provide a source of ferrous oxide which returns to the bath for further oxidation of carbon. This point has been adequately covered by Mr. Howson.

Although the origin of the silicon and manganese increments in the acid process is not really an essential part of the theory, this point definitely warrants consideration. Dr. Whiteley suggests that the silicon is derived from the slag by reduction of silica with iron to produce ferrous oxide, which goes into the slag. Even if we assume that this ferrous oxide is subsequently transferred to the metal, and there reacts with carbon, we should surely expect to see some evidence, even if only slight, of a tendency to increased ferrous oxide contents of the slag. Although this hypothetical increase of ferrous oxide in the slag would be decreased by dilution due to increasing silica and lime contents, it is fairly clear in the example quoted that, even making allowance for this, the tendency is for iron content to decrease. It seems, therefore, more probable that the silicon increment arises from reduction of silica by carbon, as Mr. Howson suggests, and there is some evidence to believe that the hearth may play an important part in this reaction. At the same time the simultaneous increase in manganese in the metal suggests that we must not ignore entirely the part played by the covering slag.

It is perhaps unfortunate that the results of only one cast were included in the paper, as this may have created an impression that Dr. Jay's considerations are based on insufficient evidence. This is not so ; there were other casts, but the data and sampling of these were not so complete or thorough as in the example quoted. At the same time it is regretted that there were no temperature recordings, as these would have added greatly to the interpretation of the data.

I am a little surprised that there has been no comment on what may be one of the most significant suggestions in the paper, namely, that the state of oxidation towards the end of the ore period when the carbon is still high (1·11%) is 2–2½ times greater than when the carbon is much lower, *i.e.*, towards the end of the limestone boil (0·33%). Some measure of interdependence of carbon and oxygen contents is essential to most theories concerning the elimination of carbon. However, the higher state of oxidation in the early stages is in line with accepted views on the partition of ferrous oxide between metal and slag, such that increase of ferrous oxide in the slag results in an increased ferrous oxide or state of oxidation in the metal. In fact Körber* has determined this partition for both MnO–FeO silicate slags and for FeO–CaO slags and has found good correlation between ferrous oxide in metal and slag of 0·0095. In practice, therefore, the oxide content of the metal may be expected to follow, to some extent, the variations of iron oxide in the slag. In acid practice the iron oxide in the slag is usually higher in the early stages of refining than in the later stages (in Dr. Jay's example the iron content of the slag falls from approximately 12% to 7·7%), so that it would be reasonable to expect a similar trend in the oxygen content of the metal. Such a trend has been shown by Dr. Jay from a consideration of the variations in manganese and silicon contents of the metal, and since it may be stated that there is no quantitative evidence of such a decrease in the metal oxygen content, the following data from another acid cast are of interest :

Time Interval	Carbon, %	Oxygen, %
Nil	0·76	0·027
33 min.	0·60	0·023
77 min.	0·47	0·017

This cast was sampled some three years ago by special methods for the rapid determination of oxygen. The decrease in oxygen content corresponding to a decrease in carbon content in the metal is clearly indicated, and had slag iron contents been available these would doubtless have shown a similar trend.

One of the fundamental differences between the acid and basic open-hearth processes is the difference between the normal trends of slag iron content. As mentioned above, in the acid process the slag iron content is generally higher in the early stages of refining than towards tapping ; in the basic process, on the other hand, the slag iron content increases throughout the refining period. Assuming, therefore, a partition of iron oxide between slag and metal, the oxygen content of basic-steel baths would tend to increase as the carbon content decreases. The following data, from a basic cast sampled at the same time as the acid cast previously mentioned, confirm these suggestions.

Time Interval	Carbon, %	Oxygen, %	Slag Fe, %
Nil	0·42	0·011	7·8
100 min. ...	0·12	0·027	12·7
136 min. ...	0·10	0·030	14·5

There is, therefore, some quantitative evidence to confirm the variation of oxygen content in the metal with iron content of the slag in both the acid and the basic processes.

* *Zeitschrift für Elektrochemie*, 1937, vol. 43, p. 457.

Joint Discussion on the Papers—

A NOTE ON VARIATIONS IN PRODUCER GAS QUALITY* *by J. E. de Graaf*

and—THE DISTRIBUTION OF FUEL IN GAS PRODUCERS† *by M. L. Hughes*

and—EXPERIMENTS ON GAS FLOW IN PRODUCER FUEL BEDS‡ *by M. L. Hughes*

Mr. **J. E. de Graaf** (Koninklijke Nederlandsche Hoogovens en Staalfabrieken, N.V., Ijmuiden, Holland) presented his paper entitled, "A Note on Variations in Producer Gas Quality."

Mr. **M. L. Hughes** (British Iron and Steel Research Association, Swansea) presented his two papers entitled, "The Distribution of Fuel in Gas Producers," and "Experiments on Gas Flow in Producer Fuel Beds."

Mr. **M. W. Thring** (British Iron and Steel Research Association, London) : Interest in gas producers is rare, like potatoes ; they are both very much lacking, due to the world economic situation. However, I think that in both cases this is a temporary situation, and that interest in gas producers will come back, just as we hope that potatoes will. The future of coal for firing steel furnaces is quite certain If this meeting was dealing with oil firing there would be a larger attendance, but in five years' time it will probably be the other way round. Whether the gas producer will survive as a

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, pp. 183–190.

† *Ibid*, 1947, vol. 156, pp. 55–74.

‡ *Ibid*, 1947, vol. 156, pp. 371–379.

method of burning coal for firing furnaces, or be replaced by direct coal firing, or alternatively, whether all coal will be carbonized at the colliery and only coke provided, is another matter; but I think that the gas producer is likely to be very important for one basic reason, that it provides a means of giving a more stable fuel to the steelmaker than does coal.

Mr. de Graaf's paper emphasizes that the real function of a gas producer is to give to the furnace a fuel which has a more constant condition than the fuel that comes into the works, so that the method of running the gas producer is primarily concerned, with altering the producer so that the gas comes out in much the same condition, though the coal which goes in is very different. It is the aim of gas-producer research to do this, and it is worth paying quite a high price to get that steady condition.

These three papers fit together very well indeed because Mr. de Graaf's paper provides a large-scale verification of the ideas which Mr. Hughes has put forward, and Mr. Hughes provides a method of solving the problem which Mr. de Graaf poses. They both emphasize the importance of channelling and segregation of small and large fuel. Mr. de Graaf shows how very important those things in fact are for the furnace user. Mr. Hughes suggests methods of solving those problems, and is wrong in saying that his paper goes only so far as the preliminary work, because he does make practical suggestions as to how to make improvements.

In his paper (p. 183 of the October *Journal*, 1947) Mr. de Graaf refers in a very unemotional way to the conditions under which his work was done, conditions which are strange to the English steel industry and where the main aim was to get as little steel out of the works as possible. One may imagine what it must be like to work under those conditions, and it is remarkable that such an interesting piece of work has resulted. This work on tar content is something which has been wanted for many years; a systematic study of the variations of the tar in producer gas and their effect on the flame is essential, and he has produced some most interesting results by undertaking such an investigation. The effect of fines on the tar seems to me most extraordinary, especially in view of the fact that the fines have the same amount of tar in them. I am not quite happy about his explanation that it is entirely a question of speed, but if it is, a good antisegregating device of the kind discussed by Mr. Hughes should solve the problem. I am not happy about that, however, and I must say that the whole kinetics of the formation of tar under those conditions seems to require some more work.

In that connection, I should like to ask Mr. de Graaf whether he has considered actually burning a small amount of the producer gas in a standard burner and measuring the luminosity of the flame. I have thought for some time that it would be interesting to have a baby furnace with a little burner like a bunsen burner and a radiometer sighted on it, and so measure and record the luminosity of the flame produced under standard conditions. That would be a valuable tool for the steelmaker as it would enable him to see whether conditions were being kept steady.

Conclusion No. 3 in Mr. Hughes's second paper (p. 379 of the July *Journal*, 1947) does not agree with work which we did in B.C.U.R.A. on a full-scale producer. We put some coal in and got inside it and measured the velocity distribution across the bed with a velometer, and we found that quite a small hollow in the surface of the bed could produce a considerable increase in velocity at that point; but the whole of our work confirms what he says about segregation affecting the flow pattern enormously. Obviously segregation is the chief bugbear, and in future work on gas producers it will be necessary to decide whether really intensive work will be done to prevent segregation or whether sized fuel is essential. I think that the colliery people will tell us that sized fuel is quite impossible, and it looks as though segregation has to be avoided at all costs, which emphasizes the importance of this work.

On the question of clinker adhesion, I wonder whether the use of carbon linings in the gas producer in the lowest region has been considered. In view of all the work done on blast-furnaces in that connection, it is an interesting point. I know that a carbon lining has been used in a water-gas generator, but I do not think that it has been applied in a gas producer.

I think that the gas producer has a very considerable future. I do not think that it has the kind of future which Siemens imagined for it—a gas producer at the bottom of a coal mine, with the gas coming up the shaft under its own buoyancy and being distributed over long distances by the buoyancy in the shaft. He intended to take out the clinker and put it straight back into the seam, cutting out a lot of mess on the surface. I myself think that the function of the gas producer is to produce a steady fuel for a furnace, and to that extent its function is somewhat similar to that of a mixer in steelmaking. We get coal of variable composition coming in and want something of fairly constant utility to come out. That is the function which the gas producer has to serve, and so the two problems with which future research on the gas producer has to deal are first, the problem of segregation, and secondly, to find a really satisfactory method of handling the ash in a gas producer; it is the difficulties of the ash disposal which are preventing the use of preheat and oxygen enrichment and many other developments in gas producers which we should like to see.

I should like to ask whether gas producers must be round. I know that Dr. Allan, of B.C.U.R.A., is working on this subject. I should like this matter to be considered, because gas producers are always thought of as being round or very nearly round, or at least square. It has obvious limitations with regard both to segregation of the fuel and ash disposal, and neither of those problems has yet been solved, though these three papers bring their solution a great deal nearer.

Mr. **A. T. Grisenthwaite** (Power Gas Corporation, Ltd., Stockton-on-Tees): As a visitor, I should like to express my appreciation of being able to take part in this discussion. I have read the two papers by Mr. Hughes with considerable interest. His work is entirely concerned with gas producers producing hot gas, whereas my own experience has been mainly in the design and operation of producers supplying cold, clean gas and therefore of usually gasifying a non-caking or only slightly caking fuel. The technical operation is different, but the fundamentals are the same.

There is one point which I would emphasize even more than Mr. Hughes did, and that is that in a gas producer we have to distribute our fuel evenly, we have to distribute our blast evenly, and we have to remove our ashes evenly, and these three things are all interrelated and all hang together. I have found that if we take one contour of fuel bed it may be perfectly satisfactory for one type of grate or blast distributor, but when used with another type of grate the results are very poor. In the same way, the method of removing the ashes affects the contour of the ash bed, and that in turn affects the blast distribution, and so will affect the contour of the fuel bed required to meet that.

It seems to me that the contour of the fuel bed or the

inequalities in the fuel bed, may be masked or marred by the particular grate or ash-removal method employed. In the same way, different gradings of fuel and different types of fuel affect the contour which is needed. For instance, anthracite tends to break up, when crushed, along flat planes, so that you get a more dense fuel bed than with coke, and the contour required for the same grading is probably entirely different.

I think that Mr. Hughes gives us a line of attack, and we can learn a good deal from it, but I do not think that we can correlate the results on different types of producer, though we can correlate them for one particular producer.

With regard to Mr. de Graaf's paper, I was a little surprised by the correlation obtained between the tar content and the volatile content of the fuel. I can appreciate some sort of correlation over a limited range of volatile matter, but I should not have expected to get it over a range of from 28% to 40%. I should like to ask the author whether he has carried out any tests on distilling or carbonizing the various fuels under the conditions which he mentions, to determine whether the theoretical tar content varies with the volatile content because from my own experience on different classes of fuel the volatile does not necessarily correlate with the tar. Can he say whether the correlation is due to some other factor, such as the rate of gasification, which was very much slower with the low-volatile fuels than with the high-volatile fuels ? With the low-volatile fuels he gets on to the caking range and may thus get more channelling than he would with the high-volatile non-caking fuels.

Dr. **R. Wild** (Imperial College of Science and Technology, London) : As Mr. Hughes has dealt at some length with the distribution of fuel in a gas producer, I thought that it might be of interest to mention some experiments which we have carried out at Imperial College on the effect of fuel distribution on the working of a small-scale model producer. The model was a 1/24-scale replica of a simple static producer fitted with a grate consisting of an open pipe covered with a conical hood. No provision was made for ash removal, so that the operation of the producer was limited to one loading of the fuel. The producer was fitted with a normal bell and hopper and a mechanical charging device designed to give uniform distribution by directing part of the charge to the centre, part to the walls, and part intermediately. Both of these charging mechanisms could be moved in a vertical plane, so that the distance fallen by the fuel before it hit the bed surface could be kept constant. The fuel used was a coal having a wide irregular grading, so that any segregation effect inherent in the charging would be enhanced.

A control experiment was carried out in which the fuel was intimately mixed and loaded by hand. It was ignited electrically, and the air flow was maintained at a constant low rate. The temperature was recorded throughout the run, and gas samples were taken at suitable intervals which were afterwards analysed for CO_2, CO, and O_2. Similar experiments were carried out with the producer loaded by means of the normal bell and hopper and also by means of the compensated mechanical charging device.

Under the conditions of these experiments, it is not surprising that in all cases the percentage of CO_2 is high, and that of CO correspondingly low. The percentage of CO is a maximum in the case of the hand-charged intimately mixed fuel bed, and only slightly less with the fuel bed obtained by compensated mechanical charging, but in the case of bell-and-hopper charging the CO content of the gases is considerably less.

More interesting than this is the fact that both with hand-charged intimately mixed beds and with beds obtained by compensated mechanical charging, the O_2 content of the gas rapidly falls to below 1% and remains around this figure for the duration of the run, a period of some 2 hr. In the case of the normal bell and hopper, however, while the oxygen content falls in a similar way to around 1% it rises again almost at once, so that after a further hour it is about 8%.

The top temperature in the case of a hand-charged bed, and also in the case of a bed obtained by compensated mechanical charging, rises to about 300° C. and then slowly falls ; but in the case of a bed obtained by a normal bell and hopper, while the temperature rises similarly to about 200° C. it then falls slightly and remains at about that figure for the duration of the experiment.

These results very definitely suggest marked channelling in the case of charging by means of a normal bell and hopper, while in the case of compensated charging, using a device for deflecting the material across the bed in such a manner that a uniform bed is obtained, there is no channelling ; so that under those conditions, using a coal with a very wide irregular grading, greatly improved operation could be obtained in our small-scale model by the use of compensated charging.

Dr. **G. W. C. Allan** (British Coal Utilisation Research Association) : As one who has studied gas producers, I should like first to express my appreciation of Mr. Hughes' very substantial contribution to our knowledge regarding them, using model technique. He has most thoroughly explored their possibilities. Perhaps the most important conclusion made by him is the analysis of the consequences of faulty fuel distribution, whose ill effects are caused—as far as channelling is concerned—by the segregation of the coarse constituent through rolling downhill into the valleys of the fuel bed. This would seem to explain much of the channelling troubles at present being met with. The work, however, indicates the limitations of working with cold models, which suffer from the absence of an adequate theory of similarity of flow of granular solids, and certainly any theory of similarity of flow from sprinkler-fed mechanisms. Models, moreover, do not indicate the effect of combustion on the flow. This is particularly shown in Figs. 2 and 3 in his second paper, where the nature of the ash is shown to have a very marked effect upon distribution, and the fact that one is unable to draw any marked conclusions therefrom is the result of our lack of information regarding the nature of the permeabilities to gas flow in actual fuel and ash beds.

Expressed in its most practical terms, our problem in producers is so to arrange these permeabilities as to produce even reaction conditions throughout the fuel bed which remain stable and are not upset by chance disturbances or segregations. It is clear that model experiments will have to be supplemented by other methods of studying the problem if the work is to be carried further.

Arising more directly from the model distribution experiments, it is clear that the levelling bar or rake is worthy of further study, as its performance can now be calculated by the extent to which it counteracts the segregation of coarse coal sizes in the valleys on the top of the fuel bed. Furthermore, as the fuel of the future seems likely, from supply conditions, to be a 1-in. slack, work on segregation is probably very important. The form of blast-hood and the shape of the lower half of the producer shell also warrant further study, because there is some evidence from full-scale work which we

have done, and also from the work of Mr. Hughes, that they exert considerable influence on distribution.

Mr. Hughes was rather apologetic in his remarks about bells, but it may be pointed out that if, in the future, producers are ever required to operate at elevated pressures, then rotating shell designs will be at a disadvantage and the bell or some other form of central feed may come into its own again.

Mr. Thring asks why producers are always round. The main answer is probably that this shape was found to lend itself to better distribution than those of square cross-section, which seem also to have been tried. One interesting early German producer may, however, be mentioned; this was of annular cross-section with the inner circular surface bounded by a brick column. It has been revived in the Pintsch-Hillebrand design of gas retort for total gasification of brown coal or peat.

Dr. **A. H. Leckie** (British Iron and Steel Research Association, London): I am sure that Mr. Hughes will forgive me and not suspect me of lack of interest in his work if I confine my remarks mainly to the paper by Mr. de Graaf. I have not been closely enough in touch with the work of Mr. Hughes to be able to do justice to it, and all that I would say in this connection is that in dealing with the importance of the sizing of coal I should not like to share Mr. Thring's pessimism about the possibility of getting sized coal. If Mr. Armstrong were here, I am sure that he would put this point very forcibly indeed.

Just before the war we looked at the results from a number of gas producers, obtained as the result of a questionnaire, and correlated the gasification rate with the voidage calculated from the sizing of the coal. Not surprisingly, we found a very strong correlation between gasification rate and the calculated voids in the coal. If you have a sized coal which gives a nicely open bed you get very good gasification. I hope, therefore, that we shall not give up our attempts to get from the coal suppliers eventually a good sized coal. Even if we cannot do so, I think that there is still a case for sizing at the producer, if that can be done, or else briquetting the fines or doing something to improve the uniformity.

Mr. de Graaf has carried out a painstaking investigation on a type of plant which is most unpromising for scientific research. Those of us who go round producer benches find the unpleasant conditions not conducive to research work, and, as Mr. Thring has pointed out, Mr. de Graaf had the additional handicap of enemy occupation.

One of the most puzzling things that we encounter in connection with open-hearth furnaces is the constant variation of the heating power of the flame. It is just a year ago that we had in this Institute a very convincing demonstration, in the Report by Dr. Chesters and Mr. Thring, of this variation in the heating power of the flame, and Mr. de Graaf has now shown us one very good reason for it. His Fig. 1, for instance, shows that the tar content of the gas varies statistically from just below 4 to just over 7 grains/cu. ft., and this, I think, shows that the calorific value of hot crude gas will vary by about 10 B.Th.U./cu. ft. in a very random way.

That is interesting, because I have recently had the opportunity to study results obtained over a period of time from a recording gas calorimeter applied to steel-plant gas producers. Similar work was done last year by Dr. Chesters at Templeborough, but recently Colvilles have had one of these instruments running for weeks on end, and it is interesting to see the continual variation in the calorific value of the cleaned gas due to variations in the feeding rate of the coal. It goes up and down by about 15 B.Th.U./cu. ft., and if that is added to the 10 B.Th.U./cu. ft. due to tar variations one can see at once why an open-hearth-furnace flame must be extremely variable in its heating power. If anything could be done to even this out it would be a great advantage.

In Mr. de Graaf's paper we see the connection between tar content, moisture content, and CO_2 percentage, and these figures agree extremely well with some measurements that my colleague Mr. Toye took in South Wales at the beginning of the year. They show that moisture and CO_2 are very closely linked, and when you include tar, which also appears to have some connection with CO_2, you have a limitation on the number of investigations you need to carry out; for instance, the CO_2 content may be a good guide to both moisture and tar. It is interesting to see the close connection between the tar content and the size of the coal, which is something we had overlooked.

There are a few questions which I should like to put to Mr. de Graaf. When he says that he found that the flame heating power of the furnace varied, was that determined by any instrument or by personal observation? Has he done any work on the heating power of various producer-gas flames? What instrument would he recommend for routine measurement of the conditions of operation of the gas producer? Recently, Mr. Toye and Dr. Pearson at Sketty Hall have developed a method of estimating the moisture in producer gas, which is rather different from that of Mr. de Graaf, though I do not know whether it is any simpler. We spent some time on it, but it seems from the figures which Mr. de Graaf gives that the CO_2 measurement, which is easier to do, would be just as good. Would Mr. de Graaf agree that it is enough to measure the CO_2 as a routine control of the producer operation, or should we try to obtain some continuous measurement of the moisture itself? What percentage loss of carbon occurs in the soot and tar deposited in the main? We have always taken a figure of about 9% for total carbon loss, but from what Mr. de Graaf says in this paper it would seem likely in his case to be considerably less.

We agree strongly with him about the iniquity of introducing the air to the producer by means of a steam blast, and the lack of control which that gives. I am glad to see that in his works the steam and air controls are independent, and I hope that this will be an encouragement to works in this country.

Mr. **R. Whitfield** (Incandescent Heat Co., Ltd., Birmingham): In the early days of the war, when the subject of emergency gas producers came up and it was a question not of supplying two or three but of manufacturing two or three hundred, it was obvious that something had to be done about the design to achieve some standardization. We decided that two of the most important things, in view of the varying fuels which were to be gasified, were the entrance of the blast into the producer and the method of feeding fuel from the top. One conclusion was that there must be a carefully graduated entrance of air and steam into the bottom of the producer, by means of louvres and carefully graduated areas to suit the average fuel.

The second problem was the feeding of the fuel. We tried all sorts of bells, and thought that the bell is one of the most important parts of the gas producer, but often neglected. After trying square and round bells as well as all sorts of curious shapes, we decided on one which, as far as we can tell, is distributing the fuel very uniformly. We arranged for a bell in the form of an equilateral triangular pyramid. If you take an equilateral triangular pyramid and twist the top round to, say, about 60°, that seemed to us to give a very good

distribution of fuel over not only small producers but also large ones. We seem wedded to the round type, but think that some improvement can be effected in the feeding of the fuel by adopting the triangular shape.

With regard to what has been said about tar and fines, we have noticed that over and over again, but really think that it is a function of the size of the fuel. The tar effect in our case is very different when we are dealing with a uniform fuel, but the tar effect is more predominant when we have an admixture of small fuel; which leads us to think that owing to the time element and the temperature, the volatiles come off the small fuel more quickly than the big. The increased surface of contact in small fuel has a profound effect on the evolution of tar.

Mr. **M. L. Hughes** (British Iron and Steel Research Association, Swansea): Mr. de Graaf's paper is very interesting, and also rather unusual, because he concentrates on one or two points and deals with them very thoroughly instead of giving a more general treatment to the whole subject.

The paper gives the impression that he was making his producer gas under what South Wales people would consider to be very favourable conditions indeed. His definition of fines is material under $\frac{3}{8}$ in., and he speaks of 10% of that grade. There is a considerable amount of scientific control, and I am surprised to find that the composition of the gas is not better. In Fig. 3, showing the variations in CO_2 content during a period of "constancy," the proportion of the diagram which lies to the right of 10% of CO_2, *i.e.*, more than 10% of CO_2, is rather surprising, using such good coal and scientific control. We in South Wales would define fines as material under $\frac{1}{8}$ in., not $\frac{3}{8}$ in., and it is quite customary to have 30–40% of that, but even under those conditions the gas made would, I think, be more constant than that given in Fig. 3.

The author gives, in Table III, variation of gas composition with type of coal used. To draw a parallel with South Wales practice, we should have to go almost to the bottom of the list, to coal of type *H*, with a throughput of 1·2 tons/hr., and 30% of volatile matter, and that being fairly well-screened coal. In South Wales they use coal of that volatile content not screened, and with a wide size ratio. It is caking as well, and the ash fusion point is low. However, even under those conditions they would not accept 10% of CO_2 and 18% of CO as a typical analysis and would probably claim that their CO_2 in the producer main averages 6–7%.

The question arises, therefore, why the author's gas was not better. It seems to me that it is something to do with the channelling which he emphasizes so much. There is certain evidence in the paper that it is so, because he refers to the increase of humidity round the perimeter, 10 in. from the wall. If there is a porous zone of that width it might account for it, but why is that zone there? Is it anything to do with the feeding mechanism? It is a Morgan producer, or something similar, judging from the author's description of it. If it is a Morgan, how were the flappers arranged?

In addition to those general remarks, I should like to ask for some additional information. My first question relates to the absence of oxygen determination in Table II. The author gives an analysis of the gas, with serious channelling, showing 15·7% of CO_2 and 7·3% of CO. I should have expected some oxygen there, say 0·5% or even 1%, but he gives no oxygen at all. Was it determined, and, if so, was it absent?

In Table III he says that the coal was fairly well screened. It would be useful to know what size is represented by "well screened." Roughly, what would the sieve analysis be?

Towards the end of the paper, he remarks that as the volatile-matter content increases, the producer works colder; that is, the younger coals high in volatile matter work colder than the older coals low in volatile matter, and he says that this is due to the fact that the vaporization of volatile matter requires heat. He does not say anything about the parallel variation of moisture content. In these coals with 39% of volatile matter the inherent moisture also goes up considerably, so that if you work on the one hand with 30% of volatile matter and 1½% of inherent moisture, and then on the other hand work with 39% volatile and perhaps 6–8% inherent moisture, that increase of moisture, which has to be vaporized, should also contribute to the coolness of the furnace. I would like him to give us some idea of the moisture content.

AUTHORS' REPLIES

Mr. **J. E. de Graaf**, replying to the discussion on his paper, said: Mr. Thring did not feel happy about the speed of the gas in the voids of the coal-bed as the reason for the variation in tar. I must confess that I feel the same doubt about it, but I could not find another factor of any real importance. It is perhaps useful to state here, also in connection with other remarks made in the discussion, that the differences of speed of the gas in the fuel bed envisaged here will not be eliminated by an anti-segregating device. When the coal is fed along a radius (as in the Morgan machine) and every minute exactly the same amount and mixture of coal grains fall on to the fuel bed, then, quite apart from the influence of the gas, the resistance to flow of gas in the fuel bed will vary statistically and thus the speed of the gas also. The deviations from the mean speed will presumably increase when the amount of fines increases from zero, possibly decreasing again when the percentage of fines is raised to 100. The statistical variations of speed in the fuel bed are considered to be important in promoting the influence of fines in the production of tar. The decreasing rate of gasification with increasing amount of fines of course accounts for some decrease in tar yield, but in my opinion not sufficiently. With regard to the baby flame as a check on constant gas quality, we did in fact consider such a possibility, but by the time that this investigation was finished there was no use for such a flame, because the works had to be shut down, and after the liberation we started on oil, so that there was no need to continue this work.

It has been questioned whether the relation between tar content and volatile matter is as great as is shown in the paper, and whether that might be partly due to the change in gas volume. It certainly has that influence, and the gas volume *is* increased, that is definitely one of the reasons. Apart from that, my impression—it is only an impression—is that the continental coal, and especially the Ruhr coal, which we had to fire in the producer, is in this respect different from what we are accustomed to in the British Isles. In our case the correlation was very definite although there was, of course, some scattering around the average. Nearly all the coal we used was non-caking, except for the coal with 24% of volatile matter. We did not do any separate distillation experiment on those coals, mainly because we came across that distillation experiment in the laboratory only at the end of the investigation. On the continent, the correlation between tar produced and volatile matter is well known.

It is very gratifying to hear from Dr. Leckie that his work has confirmed the relation between CO_2 and H_2O. This relation, however, is, in our experience at any rate,

not so strong that I would recommend him to measure the CO_2 only ; I would certainly, from my experience, recommend him to measure the humidity also, as we planned to do ourselves but did not actually do because of the change-over to oil.

The fluctuation of luminosity of the open-hearth flame was not measured solely by light intensity using the eye ; we did use some instruments. We used some rather funny instruments, perhaps, but we also used more serious ones, such as the Moll thermopile.

The percentage loss of carbon in soot is, I think, not as high as 9. What one takes from the mains seems to be soot, but if it is rubbed between the fingers and looked at through a microscope, or even a magnifying glass, it will be found that what is below the sooty surface is really coke, and perhaps ash. If one determines the ash content of what is in the mains, it will be found that it can be as high as 20%. The total percentage loss of carbon in our mains was 3–4, excluding the ash in the soot.

Mr. Whitfield says that the tar is evolved more quickly from the fines than from the coarse particles. In general that is perhaps true, but I do not think it means that the fines can be added to the coarse particles without difficulties. It would mean that from that point of view at least the smaller sizes of coal would be advantageous under suitable conditions.

Mr. Hughes was astonished by our low gas quality. That was not due to the fact that we did not want a better gas during the experiments. The amount of fines is certainly rather small, and the volatile matter is rather high. I think that the possibility of reduction of CO_2 and water by the coke, *i.e.*, the reactivity of the coke that is produced by the distilling process in the upper layers of the fuel bed, has something to do with it, apart from the melting point of the ash. The melting point of the ash with many continental coals is far lower than that to which one is accustomed here. Moreover, the temperature is sufficiently low for reactivity to play a part. That reactivity of the coke does play a role is in my opinion shown by the rather high moisture content of the gas and by the rather low rate of gasification.

How much channelling we had during normal operation is quite a different story. We had a lot, but not during these experiments. My impression was—and I often looked into the producer to see whether there were any channels—that during these trials the channelling was very low indeed. It was very seldom that we had a channel ; we took special care about that.

We had a Morgan producer, and so you know the feeding mechanism. The best flapper arrangement, found empirically, was exactly as proposed by Mr. Hughes. It was our impression that the possibilities of regulating the streams of coal coming down on to the bed could be greater than they are with the Morgan mechanism.

Mr. Hughes referred to a width of 10 in. near the wall where the moisture content was higher. That has to be understood in this way ; that if you take the points and draw a nice curve you can extrapolate from the inner side and say that that is the position, though you cannot see it ; but only within a range of perhaps 2–3 in. was it really much higher than in the middle.

The oxygen was determined, and during those trials no oxygen was present. The size of the coal that we used varied from about 1 in. to 2 in. as a rule, and the moisture content of the coal was round about 6–8%, speaking from memory.

Mr. M. L. Hughes, in reply, wrote : Mr. Thring began with an economic survey with which I am in entire agreement. The potential value of the gas producer lies in the fact that it can be adapted to use poor materials, leaving us our better quality coals for more important purposes such as the production of valuable chemical products. The same argument applies to the burning of oil and it is significant that in America there are signs of a return to gas producers. Regarding the velometer experiments referred to, I should like to say how much I am indebted to the publication, " The Flow of Air in a Gas Producer," by Dr. Rosin and Mr. Thring, in which the results of those experiments are given. Some of the results were very surprising, particularly the fluctuation of air velocity with time at a given spot, and I am not now going to venture on any explanation of those results.

He suggested that clinker adhesion might be overcome by the use of carbon linings. No doubt he is aware of the fact that such adhesion is eliminated by the use of water-cooled walls.

Mr. Grisenthwaite said that the fundamentals for successful operation of gas producers are correct distribution of the fuel, even distribution of the blast, and uniform removal of the ash. If the first of these were achieved the second requirement would follow almost automatically, if ashing were uniform. Unfortunately, mechanical ashing is not what it ought to be and uniform removal of ash around the producer is not always achieved. I would repeat the statement that the ash bed and the fuel bed should be regarded as of equal importance and that any irregularity in ashing is likely to be reflected in the producer performance.

The size of grate is certainly related to producer operation. If a very wide grate is used so that the air enters relatively near the walls, there would probably be a greater tendency to wall effect than would arise with a small grate and a shallow bed.

I was very interested in Dr. Wild's description of his experiments. I know that he has done a great deal of work on these lines. It is rather surprising that he should find so much oxygen in the gas from his experimental bell-and-hopper producer ; the presence of 8% of oxygen in the gas is certainly not representative of the results obtained with bell-and-hopper charging, even with wide size ratio coal. Even when gas is taken from immediately above a channel it is usually much lower in oxygen than 8%, while the average in the main is always down to a few tenths per cent.

Dr. Allan has quite rightly drawn attention to the effect of combustion on gas flow through the bed. His reference to Figs. 2 and 3 in the second paper, where the effect of an adherent clinker is shown, could be supplemented by reference to Fig. 12. In this experiment an attempt was made to show the effect of the existence *in the ash bed* of zones of varying ash condition resulting from hot and cold zones in the fuel bed above. It is the irregularity of the combustion which causes trouble and one of the aims of work on distribution is to minimize such irregularities. The use of cold models must ultimately be supplemented by experiments involving actual gasification, since the effect of caking, and of temperature variations on gaseous viscosity and other factors need to be examined.

My views on bell-and-hopper charging are described by Dr. Allan as pessimistic. I should like to make my views clear on this point. In my paper the bell and hopper is examined from the point of view of the distribution achieved by it of coal of wide size ratio. If the coal is sized so that segregation is of much less importance, the occurrence of an **M** contour does not matter so much, as has been shown by the gas-flow experiments. If, in addition, the coal is non-caking a thicker fuel bed may be used which will also assist matters. I have recollec-

tions of steelworks days when producers fitted with bell-and-hopper charging could be operated to give 24–27% of CO quite consistently.

He mentions the need for research on the action of levellers. The work described in the first paper did not include any study of the leveller because it was sought to separate the two variables, (*a*) the distribution of the charge as deposited on the fuel bed, and (*b*) the subsequent redistribution produced by the leveller. Work on the second question had been commenced but had to be suspended. A small leveller had been inserted into a model in such a way that it could be operated when lying along a radius or when at small angles on either side of a radius. This was done because levellers and agitators which rotate round the axis of the producer seem merely to push the fuel around in circles. This is discussed on page 68 of the paper on distribution, under the heading " Levellers and Agitators."

Dr. Leckie referred to the correlation of voidage with gasification rate. There is certainly a great difference between the gasification of, say, washed singles on the one hand and a through coal of wide size ratio on the other. Using a Morgan producer the maximum gasification rates would be about 3 tons and 1½ tons an hour respectively.

Mr. Whitfield's remarks concerning bells were most interesting. The idea of a twisted triangular pyramid instead of the conventional cone is certainly novel. I cannot visualize how it would work but I have noted the point with interest.

Author's Reply to the Discussion on—OBSERVATIONS ON CONDUCTING AND EVALUATING CREEP TESTS* *by W. Siegfried*

The contributions to the Discussion on Mr. Siegfried's paper will be found on pages 382–384 of the November, 1947, issue of the Journal.

Mr. **W. Siegfried** (Sulzer Brothers, Ltd., Winterthur, Switzerland) wrote : In reply to Mr. Oliver's contribution, the dimensioning of blade-root fixings for gas turbines is an extremely complicated problem involving a number of variables the exact influence of which it is very difficult to ascertain, and in these circumstances it is not surprising that different research centres should have chosen different methods of approach. The most important factors to be taken into account in the choice of dimensions are the form of the teeth and the behaviour of the material.

The best method of approach to so complicated a problem is always to endeavour to isolate each of the influences, for it is only by this means that the problem can finally be mastered as a whole, and indications made, for instance, on the consequences to be expected from the use of a new steel.

We have sought a solution to the problem by treating first of all the two separate aspects of it mentioned above, our aim being to arrive finally at a synthesis of the two and thus at a general solution. In order to keep our work within limits laid down by a metallurgical conference, we contented ourselves in the paper under discussion with the publication of the results obtained on the behaviour of the material at high temperatures.

It was extremely interesting to hear how these problems are being tackled in England, and we are duly grateful to Mr. Oliver for his information.

Concerning investigations into the most favourable form of teeth, we too have carried out photo-elastic tests. In order to make full allowances for the fact (to which Mr. Oliver also refers) that the conditions of stress resulting from creep testing vary according to circumstances, we have likewise conducted tensile tests at room temperature and sustained-load tests at high temperature on models of blade roots. The conditions developing were followed up by elongation measurements with systematic evaluation of the results, while the type of deformation and the stress conditions particularly favouring the occurrence of fracture were also investigated.

Our experience with various heat-resisting steels at high temperatures has repeatedly shown us that sensitivity to notching is a factor of very great importance, and that the points to be considered in dimensioning blade teeth for high temperatures are in many cases different from what they would be at room temperature. It proved, for instance, that a certain change in the shape of the teeth at room temperature led to an improvement, while the same modification of the teeth in the same material at high temperature resulted in a reduction of strength. It is perhaps interesting to note that the steel used in these tests gave high elongation figures in the smooth-bar sustained-load test at high temperatures and therefore cannot be regarded as brittle.

With regard to Mr. Bardgett's contribution, our attention was first drawn to the significance of sensitivity to notching by observations of the effect of measuring marks on steels submitted to sustained-load tests (*see* Fig. 13). We are at present engaged on a large series of tests with various forms of notch, but these tests are not yet completed and cannot be finally evaluated. What we have found, however, is that sharp shallow notches are very dangerous for many steels, and that this sensitivity to notching is particularly pronounced at loads which result in small elongation values in smooth bars subjected to sustained-load tests.

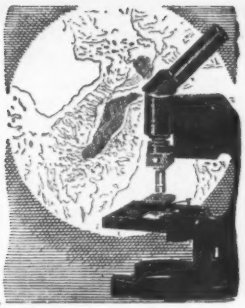
In reply to Dr. Sykes, the reduction in the strength of the steel illustrated in Fig. 5 is to be attributed primarily to the slipping apart of the grain boundaries, as metallographic investigations have revealed. This slipping at the grain boundaries is to be explained in the steels tested by the formation of ferrite there. It is therefore easy to understand that other physical processes leading to the weakening of the grain boundaries may also lead to a similar form of sustained-load curve, without any changes in the magnetic saturation being observed.

Our investigations showed that the fractures usually began at the surface of the notched bars and went inwards. Kuntze's theory does not allow of any statement on the formation of the cracks, as its purpose is to establish the resistance of the material to separation and not the influence of a stress concentration. From the fact—as already mentioned—that sharp shallow notches greatly accelerate the occurrence of brittle fractures, it must be concluded that it is precisely the stress concentrations at the base of the notch which exert the chief influence in the formation of the crack.

* *Journal of The Iron and Steel Institute*, 1947, vol. 156, June, pp. 189–207.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



First Report of the Methods of Testing (Corrosion) Sub-Committee

SYNOPSIS

An account is given of the researches of the Methods of Testing (Corrosion) Sub-Committee on the basis of which Provisional British Standard No. 1391 : 1947, "Performance Test for Protective Schemes Embracing Stoving Paints Used in the Protection of Light-Gauge Steel and Wrought Iron against Corrosion," was compiled. After investigations of a number of different methods of testing, a sea-water spray test devised at the Armament Research Department was selected as the most suitable for this purpose and was standardized to ensure reproducibility of the results. Reasonable standards of performance in this test for protective schemes embracing single coats of stoving paints applied over phosphated or non-phosphated steel were determined by means of tests on typical industrial finishes of these types, the results of which are recorded.

The report concludes with an analysis of the statistical aspects of the test contributed by the Chief Scientific Adviser's Division of the Ministry of Works.

Introduction

The Need for Performance Tests for Protective Schemes Applied to Light-Gauge Steel Parts

As a result of the extensive use of prefabricated light-gauge steel components in the Government's programme of post-war construction of dwelling houses, the Ministry of Works became interested in the question of protecting such material from corrosion, and at the Ministry's suggestion the British Standards Institution, on 22nd November, 1944, set up Technical Committee ISE/28, "Standards of Protection for Iron and Steel Used in Building Construction," to deal with the problem. After devoting some time to the consideration of various types of protective coatings likely to be suitable under the conditions to be met, this Technical Committee issued some general recommendations for the guidance of industry.* It was apparent, however, that the best way to achieve the desired end was not to lay down hard and fast rules as to the protective schemes themselves, but to specify the minimum performance acceptable. As the development of performance tests, involving as it did investigations of testing methods, was not within the province of the British Standards Institution Committee, this part of the work was handed over, with the ready acquiescence of that Institution, to the Methods of Testing (Corrosion) Sub-Committee of the Corrosion Committee—then a Joint Committee of The Iron and Steel Institute and the British Iron and Steel Federation, reporting to the Iron and Steel Research Council—which was set up on 6th November, 1945, under the chairmanship of Dr. J. C. Hudson.

Terms of Reference and Constitution of the Methods of Testing (Corrosion) Sub-Committee

The terms of reference of the Sub-Committee were :

(1) To investigate and report on the validity of *methods* of conducting corrosion tests on iron and steel and on protective schemes used for these materials.

(2) To devise new methods of testing in this field where necessary.

(3) To collaborate in these matters with the British Standards Institution and other interested bodies and, on request, to advise them with a view to the standardization of appropriate test methods.

The organization of research for the iron and steel industry was later completely changed by the establishment of the British Iron and Steel Research Association, which took over all the research activities previously sponsored by The Iron and Steel Institute and the British Iron and Steel Federation. On 1st January, 1947, the Methods of Testing (Corrosion) Sub-Committee was transferred to the new Association. It has retained its former name and terms of

* P.D.420 "Recommendations on Methods of Protection against Corrosion for Light-Gauge Steel and Wrought Iron Used in Permanent Building Construction."

Paper MG/BF/29/47 of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 3rd November, 1947.

reference and now consists of the following members :

Mr. W. E. BALLARD	Metallisation, Ltd.
Mr. C. BRAITHWAITE	Royal Aircraft Establishment
Mr. A. E. CHATTIN	The Iron and Steel Institute
Dr. S. G. CLARKE	Armament Research Department
Mr. F. FANCUTT	Railway Executive, British Railways
Mr. K. HEADLAM-MORLEY	The Iron and Steel Institute
Dr. J. C. HUDSON (*Chairman*)	British Iron and Steel Research Association
Mr. L. H. MCDERMOTT	Ministry of Works
Mr. R. ST. J. PRESTON	D.S.I.R., Chemical Research Laboratory
Mr. C. E. RICHARDS	Post Office Research Station
Mr. R. E. SHAW	Imperial Chemical Industries, Ltd., Paints Division
Mr. G. E. SPEIGHT	The United Steel Companies, Ltd.
Mr. G. WESTON (*Associate Member*)	British Standards Institution
Mr. W. E. WRIGHT	The Pyrene Co., Ltd.
Mr. G. WITHERS (*Secretary*)	British Iron and Steel Research Association

Scope of the Present Report

The object of this report is to present the results of the experimental work undertaken to date by the Sub-Committee ; this has been conducted throughout on a collaborative basis in the laboratories of its individual members. So far, work has been devoted to the development of suitable tests for protective schemes applied to light-gauge steel components and has proceeded in three stages :

(i) *General Investigation of Accelerated Tests for Protective Schemes Applied to Light-Gauge Steel*—Sets of specimens representing a range of protective schemes applied to light-gauge steel were subjected to eight different types of laboratory test. On the basis of this work, a sea-water spray test, originally developed at the Armament Research Department, was selected as most suitable for immediate development. Other tests gave encouraging results and the Sub-Committee hopes to investigate these further.

(ii) *Reproducibility of the A.R.D. Sea-Water Spray Test*—The reproducibility of the A.R.D. sea-water spray test was then investigated by supplying standard sets of specimens to members of the Sub-Committee, who subjected them to test in their own laboratories. The reproducibility was found to be reasonably good and it was concluded that the test was suitable for specification purposes.

(iii) *Application of the A.R.D. Sea-Water Spray Test to Industrial Protective Schemes*—Finally, in order to determine suitable standards of performance that could be met by good present-day industrial practice, protective schemes were applied to specimens under practical works conditions and the panels were then subjected to the A.R.D. salt spray test in the laboratories of members.

The main outcome of these investigations is that the Sub-Committee has been able to advise Technical Committee ISE/28 of the British Standards Institution regarding the preparation of a standard performance test and that, as a result, the latter was

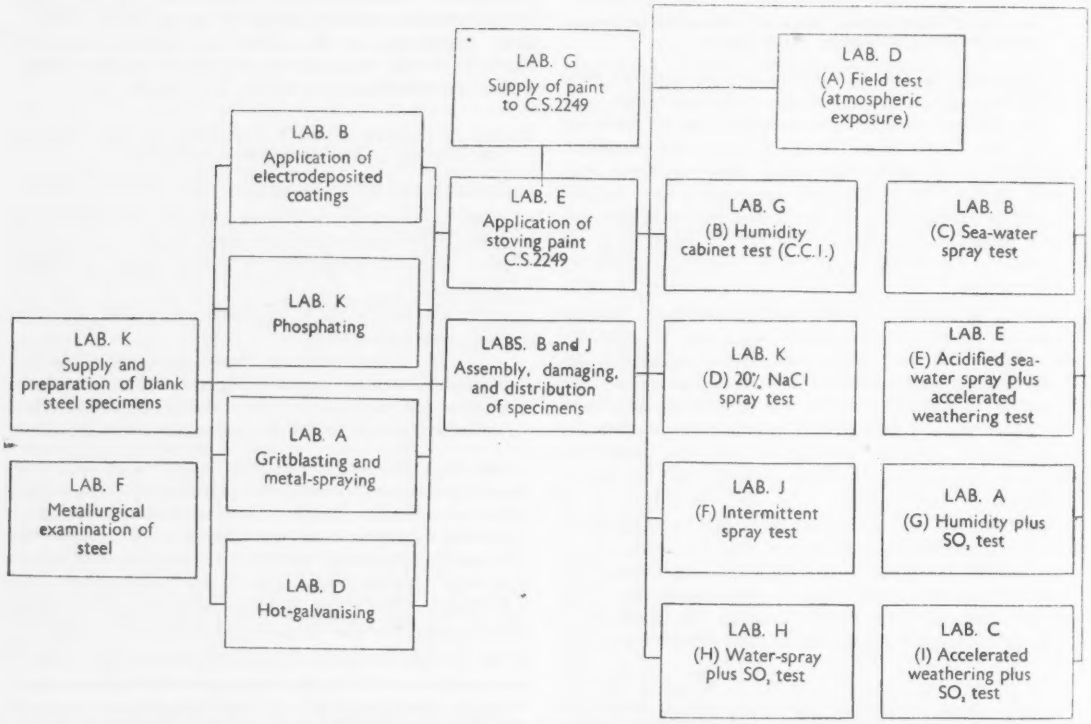


Fig. 1—General investigation of accelerated laboratory tests for protective schemes applied to light-gauge steel

able to compile Provisional British Standard 1391 : 1947—"Performance Test for Protective Schemes Embracing Stoving Paints Used in the Protection of Light-Gauge Steel and Wrought Iron against Corrosion." This Provisional Standard was published by the British Standards Institution in August, 1947.

Acknowledgments

The Sub-Committee gladly acknowledges the considerable measure of support and collaboration received from industry in the conduct of its investigations and, in particular, wishes to express its thanks to the following firms :

The Austin Motor Co., Ltd.
Briggs Motor Bodies, Ltd.
British Coated Sheets, Ltd.
Coldair, Ltd.
Electrolux, Ltd.
General Galvanizers, Ltd.
Guest, Keen & Nettlefolds, Ltd.
N. C. Joseph, Ltd.
Joseph Lucas, Ltd.
John Lysaght, Ltd.
Sentinel (Shrewsbury), Ltd.
Wallis and Co. (Long Eaton), Ltd.

In addition, the Sub-Committee's thanks are due to the Chief Scientific Adviser's Division of the Ministry of Works for contributing the section of this report dealing with the statistical design of the proposed standard performance (*see* p. 490), and to Mr. J. F. Stanners, of the B.I.S.R.A. Corrosion Laboratory, who has rendered considerable assistance in the drafting of the report.

GENERAL INVESTIGATION OF ACCELERATED LABORATORY TESTS FOR PROTECTIVE SCHEMES APPLIED TO LIGHT-GAUGE STEEL

General Experimental Programme

The organization of the experimental programme is outlined in Fig. 1. In brief, 10 similar sets of 17 mild-steel specimens were prepared. One specimen of each set was uncoated, whilst each of 16 different protective schemes was applied to one of the others. A set of specimens was subjected to each of 8 different types of accelerated laboratory test, one was exposed to the atmosphere outdoors, and the tenth set was used for examination of the protective schemes themselves.

Experimental Details

Size and Type of Specimens—The specimens measured 6 in. × 4 in. and were cut from 20 S.W.G. pickled, cold-rolled, close-annealed mild-steel sheet, such as would be used for the production of prefabricated building components.*

The blank specimens were supplied to the various laboratories in the oiled condition but were carefully degreased before the application of the protective schemes.

Types of Protective Schemes Investigated—The 16 protective schemes tested were :

1 Degreased, painted
2 Grit-blasted, painted
3 Phosphated, painted
4 Aluminium, sprayed, 3 mils
5 Aluminium, sprayed, 3 mils, painted
6 Lead, electrodeposited, 1 mil
7 Lead, electrodeposited, 1 mil, painted
8 Lead, electrodeposited, 3 mils
9 Zinc, electrodeposited, 0·05 mil, phosphated. painted
10 Zinc, electrodeposited, 0·3 mil
11 Zinc, electrodeposited, 0·3 mil, painted
12 Zinc, electrodeposited, 0·3 mil, phosphated. painted
13 Zinc, electrodeposited, 1 mil
14 Zinc, electrodeposited, 1 mil, painted
15 Zinc, hot-dipped, 3 mils
16 Zinc, hot-dipped, 3 mils, painted

Where the protective scheme comprises painting, a single coat of stoving paint was applied by hand-dipping and stoving under standardized conditions. The same paint was used throughout, namely, an off-white stoving-type primer to specification C.S.2249.

All the specimens were weighed before and after each stage in the protective treatment applied to them. A summary of the weights of the metallic coatings deduced from these weighings is given in Table I, together with approximate calculated figures for the corresponding average thickness. The average weight of the dry film of stoving paint applied to the

* A representative analysis is C 0·09%, Mn 0·30%, P 0·04%, and S 0·05%. As supplied, the steel had a Rockwell B hardness figure of 50–60.

Table I

WEIGHT AND AVERAGE THICKNESS OF THE METALLIC COATINGS

Set No.	Coating Metal	Nominal Thickness, mils	Number of Specimens	Coating Weight, g. per specimen*			Average Coating Thickness, mils
				Minimum	Maximum	Average	
4 and 5	Aluminium	3	20	5·72	8·50	7·25	3·4
6 and 7	Lead	1	20	8·01	9·26	8·66	0·98
8	Lead	3	10	23·41	27·18	24·43	2·77
9	Zinc	0·05	10	0·26	0·28	0·27	0·048
10, 11, and 12	Zinc	0·3	30	1·57	1·79	1·68	0·30
13 and 14	Zinc	1	20	5·34	5·86	5·57	1·01
15 and 16	Zinc	3·3†	20	15·53	20·62	17·68	3·2

* Total area 48·7 sq. in. † 2 oz./sq. ft. of surface.

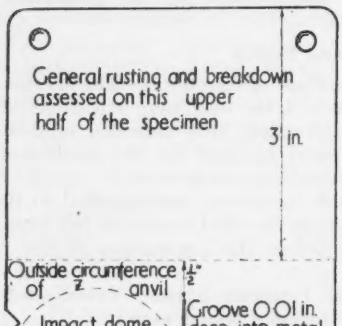


Fig. 2—Method of damaging protective schemes before test

painted specimens was 2·03 g. per specimen.* This corresponds to an approximate average film thickness of 1·05 mils, but marked deviations from this average occurred from one type of protective scheme to another (*see* p. 475).

The average loss in weight of the specimens on grit-blasting (set No. 2) was 0·69 g. per specimen, which is equivalent to the removal of a uniform layer of steel 0·1 mil thick all over the specimen,† and the average weights of the phosphate coatings were 0·17 g. over bare steel (set No. 3) and 0·10 over electrodeposited zinc (sets Nos. 9 and 12). The latter figures correspond to coating thicknesses of the order of 0·05 mil.

Full details of the application of each protective scheme were observed and are available in the Sub-Committee's files. For the present purpose, it will suffice to state that each protective scheme is adequately defined by the general description given above.

Initial Damage—It is important that a protective scheme should be able to withstand damage and should also prevent the spread of corrosion when in the damaged condition. Consequently, any acceptable accelerated test for protective schemes must give close correlation with practical conditions of use as regards their behaviour in both these respects. It was therefore decided to inflict a standard form of damage to all specimens.

The damage, which was inflicted on the front surface of the lower half of the 6-in. × 4-in. specimens, as shown in Fig. 2, consisted of :

(*a*) A vertical scratch, which just penetrated the paint film,

(*b*) An annular groove, penetrating right through the protective coatings and into the basis steel.

(*c*) An impact dome, caused by a hammer blow.

The *vertical scratch* was made by hand, using a cutting edge 0·025 in. wide and exerting sufficient pressure to penetrate the paint film or the thinnest metallic coatings. No scratch was made on specimens in which the protective scheme did not include paint.

The *groove* was cut with a **V**-shaped tool mounted in a vertical-spindle bench-type precision jig-boring machine. It was $\frac{5}{8}$ in. in dia., 6 mils deep, and approximately $\frac{1}{32}$ in. wide at the outer surface of the coating.

The *dome* was produced by means of a blow from a Stanton impact machine on the back of the specimens. The weight of the hammer was 5 lb. and the height of drop $3\frac{1}{2}$ in. The striker portion of the hammer was of steel, of roughly hemispherical shape, and $\frac{3}{4}$ in. in dia. The anvil on which the panels were set was of tubular section $2\frac{1}{8}$ in. external dia. and approximately $1\frac{31}{32}$ in. internal dia. (radiused).

Description of the Methods of Testing

General Remarks—Nine methods of testing were chosen, as follows :

A—Field test—atmospheric exposure—at Birmingham
B—Humidity cabinet (C.C.I.)
C—Sea-water spray (one spraying each day)
D—20% NaCl spray (continuous)
E—Acidified sea-water spray plus accelerated weathering
F—Intermittent spray test
G—Humidity plus SO_2
H—Water spray plus SO_2
I—Accelerated weathering plus SO_2

The laboratory tests may be divided into three groups, namely :

(i) No corrosive spray, corrosion induced by condensation alone—test *B*.

(ii) Corrosive spray without added "sulphur acid"—tests *C* and *D*.

(iii) Corrosive spray with added "sulphur acid"—tests *E*-*I*. Of these, three, namely, tests *E*, *F*, and *I*, include a period of exposure to ultra-violet light.

A—Field Tests—The field tests were commenced in June 1945, the specimens being exposed outside the B.I.S.R.A. Corrosion Laboratory, Selly Oak, Birmingham, at an angle of 45° facing approximately south, with the damaged (front) surface uppermost. The atmosphere is best described as an urban one, and observations on control specimens show that the rate of corrosion of bare mild steel exposed there is of the order of 4 mils per year.

B—Humidity Cabinet—This test was made in a standard C.C.I. Humidity Cabinet. The specimens were held vertically in an atmosphere of approximately 100% relative humidity at a temperature oscillating between 42° and 48° C.

C—Sea-Water Spray—The form of salt-water spray test in use at the Armament Research Department, Woolwich, was selected for the present purpose, as being one that requires a minimum of equipment and which does not call for great technical knowledge on the part of the operators. It consists simply in spraying with natural sea-water by a hand-atomizing spray, so as to coat the test surfaces all over with small droplets. After spraying, the specimens are enclosed within a box-like cover of sheet metal to retard

* The total surface area of a specimen is 48·7 sq. in.

† As will be discussed in the section dealing with determinations of surface roughness (*see* p. 476), grit-blasted surfaces are far from uniform.

drying-off of the droplets, a dish of water being also kept under the cover to retard the rate of evaporation. Spraying is repeated at intervals of 24 hr. (except on Sundays) and the specimens are inspected each day immediately before this. The test is conducted throughout at ordinary laboratory temperature.

The apparatus used in the present test is shown in Fig. 3. The specimens were suspended by thread from two parallel rods; dummy specimens of varnished steel were hung at each end of the row to obviate end effects. During rest periods, the specimens were about 1 in. apart, but at the time of spraying each specimen was moved along the rod to give a wider spacing.

The sprayer used was of glass and gave a spray consisting of fine droplets and not an impalpable mist. The rate of drying-off after spraying was slow. All specimens remained wet for at least 7 hr. In the case of painted specimens the droplets persisted and the surface generally remained wet for the full 24 hr., but the droplets spread on unpainted specimens, which seemed to dry sooner.

D—20% NaCl Spray—The continuous salt-spray test was carried out at room temperature in a chamber of some 50 cu. ft. capacity. A 20% solution of sodium chloride is placed in the bottom of the cabinet from which it is blown in the form of a fine spray by means of compressed air. A glass baffle plate is placed horizontally above the atomizer to remove large drops and prevent direct impingement of the spray on the specimens. Except for such short periods as are necessary for inspection and maintenance, the spray is operated continuously.

The sodium chloride solution was changed daily and its *p*H was checked by means of a glass electrode both before and after use. The specimens were hung vertically in the cabinet from a suitable rack and their positions on the rack were systematically varied at daily intervals, each specimen occupying every position in turn during a complete cycle of 17 days.

E—Acidified Sea-Water Spray plus Accelerated Weathering—This test was based on a 24-hr. cycle comprising two phases, which is in use at the Paint Research Station.

(i) During the first 8 hr. the panels were exposed to a spray of the following solution, which was not allowed to impinge directly on them:

Tidman's sea salt	...	27 g.
Sulphuric acid (sp. gr. 1·84)	...	3·74 c.c.
Water	... ...	1000 c.c.

(ii) For the remaining 16 hr., the panels were submitted to an accelerated weathering test in the following manner:

An uncored carbon arc enclosed in resistance glass and consuming 0·8–0·95 kW. across the arc was suspended eccentrically (approximately 8 in. from the centre) in a cylindrical container of about 4 ft. dia. to the sides of which the panels were attached. The container made about 3 revolutions per hour to ensure even exposure of the panels to the radiation of the arc and regular wetting by means of a fine spray of main-water suitably disposed in the container.

The same side of the panel was exposed to the arc lamp and to the acid salt-spray during each cycle.

F—Intermittent Spray Test—The intermittent spray test was made in an apparatus of the type described by T. Swinden and W. W. Stevenson,* as subsequently modified at the Chemical Research Laboratory.

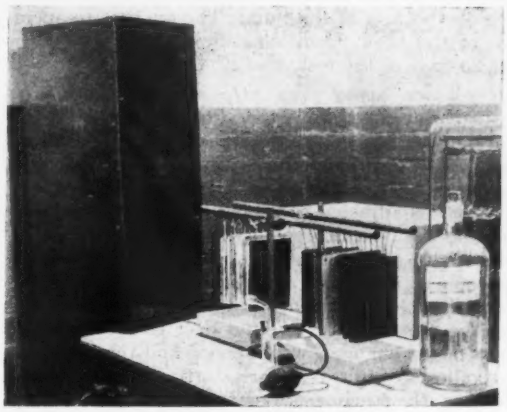


Fig. 3—Apparatus used for the A.R.D. sea-water spray test

Each specimen was mounted on a belt moving at approximately 17 in./min. and completed a cycle in 18 min. which involved successive exposures to:

(i) N/5000 ammonium chloride, N/5000 ammonium sulphate spray
(ii) Hot-air drier with addition of SO_2
(iii) Ultra-violet light
(iv) Water spray
(v) N/100 H_2SO_4 spray
(vi) Radiant heat

The apparatus was run during working hours and the specimens were stored overnight in a damp chamber containing a small amount of sulphur dioxide. It was evident from the changes in the appearance of the specimens that storage in this atmosphere caused further deterioration of the protective schemes.

The dilute solution of ammonium salts was introduced with the object of forming nuclei for the development of rusting. The remaining corrosion accelerators and the weathering factors were designed to simulate weather conditions generally.

G—Humidity plus SO_2—This series of tests was carried out in a stone tank of 20 cu. ft. capacity placed in the open air. The tank had a plate-glass cover and the specimens were suspended inside by means of glass hooks hanging from longitudinal glass rods. Air was passed through the tank for two periods of 3½ hr. each during each full working day at the rate of 12 cu. ft./min. This air was fully humidified and was artificially charged with 0·04–0·05% of the sulphur dioxide, the SO_2 content of the tank being checked three times daily. During two periods each day (9.0 to 10.0 A.M. and 4.0 to 4.30 P.M.) the specimens were sprayed with water by means of an atomizer working in a reservoir placed in the middle of the tank and fitted with suitable baffles; thus the specimens were kept moist throughout the test period.

The specimens were removed at the end of each day, examined, and stored indoors overnight in a dry

* *Journal of The Iron and Steel Institute*, 1940, No. II, p. 165P.

atmosphere. The residual solution was drained daily from the bottom of the tank. The average temperature of the tank, from three daily readings on the first 25 days of the test, was 22° C.

H—Water Spray plus SO_2—In this method of testing, developed by the Post Office Research Station, the specimens were suspended on rotating arms in a chamber in which a water-spray was being discharged and in which a jet of coal gas was burning. The jet was adjusted to burn 3 cu. ft. of gas in 8 hr. and the gas was charged with sufficient carbon disulphide to raise the sulphur oxide content of the atmosphere, calculated as sulphur dioxide, to 20 parts per million. This continued for 8 hr. each day. For the remaining 16 hr. and over the weekend the doors of the chamber were opened and the specimens were allowed to dry. Before starting the spray each morning, the specimens were washed down for 5 min. with distilled water from a paint-spraying pistol, using an air pressure of about 30 lb./sq. in.

I—Accelerated Weathering plus SO_2—The ninth method was a test cycle in use at the L.M.S. Research Laboratories, Derby. This comprises two parts, as follows :

(i) Exposure in a Gardner Research Model Twin Arc Weatherometer for 17 hr., using one spray for a 16-hr. period ; the rating of the two carbon arcs used during this time was approximately 5 kW.

(ii) Exposure for 5 hr. in a damp atmosphere produced by passing steam continuously into a glass chamber of 2 cu. ft. capacity. Throughout the third hour of this period sulphur dioxide was introduced at the rate of 15–20 c.c./min. The steam sufficed to maintain the temperature at 40° ± 5° C.

In the course of each week, the specimens were exposed to 5 periods in the weatherometer and 4 periods in the steam/SO_2 chamber. They were allowed to remain at room temperature from noon on Saturday until 4.0 P.M. on Monday.

Experimental Results

General Remarks—The main object of this investigation is to ascertain which laboratory tests give the closest indications of the relative results of the protective schemes when exposed to service conditions. The only practicable method of doing this is to correlate the results of each laboratory test with those of the field test and this has been done. It should be recognized, however, that this procedure suffers from two limitations, namely :

(i) The correlation of the laboratory tests with the field tests can only be provisional, because failure of many of the protective schemes in the latter test will take a considerable time and their final order of merit cannot yet be assessed.

(ii) The correlation is made on the basis of resistance to corrosion under conditions of complete exposure outdoors, whereas many of the articles to which the performance test will be applied, will in service be exposed to indoor atmospheres. The Sub-Committee does not anticipate, however, that this fact would lead to any marked differences in the behaviour of the type of protective schemes covered by the Provisional Standard 1391 : 1947 issued by the British Standards Institution.*

The behaviour of individual protective schemes in the various tests is incidental to the main purpose but, in view of the urgent necessity for guidance in the choice of protective schemes for light-gauge steel components, a few references will be made to the most interesting observations noted in this connection.

Although a detailed description of the procedure followed at inspections is unnecessary, it should be noted that all of these, both in the laboratory and in the field, were made in a standard manner and that systematic records of the observations are available. These records were supplemented by photographs of the front and back of each specimen taken at half-size after appropriate periods.

Results of the Outdoor Exposure Test up to 2 Years' Exposure—The behaviour of the protective schemes to date in the outdoor exposure test at Selly Oak, Birmingham, is indicated in Table II. It has been thought sufficient to report the percentage rusting on the undamaged halves of the specimens at the last inspection made before writing this report (2·0 years' exposure), together with the duration of exposure necessary to produce 1% of surface rusting. If this latter figure is accepted as the criterion of failure,† the following seven protective schemes had failed, either on the upper or on both surfaces :

No. 1 Degreased, painted
No. 2 Grit-blasted, painted
No. 3 Phosphated, painted
No. 9 Zinc, electrodeposited, 0·05 mil, phosphated, painted
No. 10 Zinc, electrodeposited, 0·3 mil
No. 11 Zinc, electrodeposited, 0·3 mil, painted
No. 12 Zinc, electrodeposited, 0·3 mil, phosphated, painted

Of the remaining specimens, four were entirely free from rust, namely :

No. 7 Lead, electrodeposited, 1 mil, painted
No. 13 Zinc, electrodeposited, 1 mil
No. 14 Zinc, electrodeposited, 1 mil, painted
No. 15 Zinc, hot-dipped, 3 mils

The other five specimens occupied intermediate positions. It should be noted that in the majority of cases, when a coat of stoving paint was applied, this had long since ceased to afford any protection.

As already stated, a final assessment of the order of merit of the different protective schemes will not be possible for some considerable time. It is probable that such an assessment will be based more suitably on the observed durations of test to failure than on the conditions of the protective schemes at the conclusion of exposure. In general, as will be noted from a study of Table II, the two orders of merit so deduced will not correspond. For example, in the present series rusting developed rapidly on specimen No. 2 (grit-blasted, painted), because, as will be discussed on page 476, the thickness of the paint film was insufficient to cover the rugosity of the surface resulting from grit-blasting. Consequently, in the early stages of exposure the condition of this protective scheme was inferior to that of scheme No. 1

* The field covered by the standard has been restricted to protective schemes embracing stoving paints (p. 489).

† *See also* the remarks on the Accelerated Weathering plus SO_2 Test on p. 473.

(degreased, painted), as is evidenced by the lower test durations to failure, 46 and 78 days, respectively, on the upper and lower surfaces, as compared with 117 and 190 days for scheme No. 1. On the other hand when exposure has been continued for 2 years, long beyond the point of failure, the advantage appears to lie with the grit-blasted and painted specimen.

A similar complication arises when considering the behaviour of composite protective schemes embracing both metallic coatings and paint. There are indications, both in the present tests and in the more extensive tests of the Protective Coatings Sub-Committee on metallic coatings used for the protection of heavy structural steel, that under certain circumstances the application of paint over a metallic coating may lead to more rapid failure of the protective scheme as a whole than if no paint is applied. This untoward result seems liable to occur if the paint is not renewed within a reasonable time of its reaching the point of breakdown; thereafter, the imperfect paint film acts as a sponge and retains moisture in contact with the metallic coating. This in turn may give rise to electrochemical corrosion, which is not usually pronounced in the case of straightforward atmospheric exposure, and lead to rapid breakdown of the protective scheme. Be this as it may, it will be noted from Table II that the duration of test to failure was less for protective schemes Nos. 11 and 12, in which paint was applied over electrodeposited zinc 0·3 mil thick, than for scheme No. 10, protected with 0·3 mil of electrodeposited zinc alone. The test durations to failure on the upper surface for these protective schemes in the order given were 563, 462, and 738 days. It is clear from the behaviour of protective scheme No. 3 (phosphated, painted) that the effective life of the single coat of stoving paint used in these experiments was of the order of 190 days on the upper surfaces. These results should, therefore, not be interpreted as adverse to the value of phosphating over a zinc-coated surface before painting when a more durable painting scheme is used. As it was, the specimens of schemes Nos. 9 (zinc, electrc

Table II

CONDITION OF THE PROTECTIVE SCHEMES AFTER 2 YEARS' EXPOSURE OUTDOORS AT BIRMINGHAM

No.	Protective Scheme — Designation	General Rusting, % — Front	General Rusting, % — Back	Duration of Test to 1% Rusting, days*	
1	Degreased, painted	20	2	117	190
2	Grit-blasted, painted	5	2	46	78
3	Phosphated, painted	2	0·2	190	—
4	Aluminium, sprayed, 3 mils	Nil	0·1	—	—
5	Aluminium, sprayed, 3 mils, painted	Nil	0·1	—	—
6	Lead, electrodeposited, 1 mil	0·2	Nil	—	—
7	Lead, electrodeposited, 1 mil, painted	Nil	Nil	—	—
8	Lead, electrodeposited, 3 mils	0·2	0·5	—	—
9	Zinc, electrodeposited, 0·05 mil, phosphated, painted	10	0·5	190	—
10	Zinc, electrodeposited, 0·3 mil	1	Nil	738	—
11	Zinc, electrodeposited, 0·3 mil, painted	50	0·1	563	—
12	Zinc, electrodeposited, 0·3 mil, phosphated, painted	50	Nil	462	—
13	Zinc, electrodeposited, 1 mil	Nil	Nil	—	—
14	Zinc, electrodeposited, 1 mil, painted	Nil	Nil	—	—
15	Zinc, hot-dipped, 3 mils	Nil	Nil	—	—
16	Zinc, hot-dipped, 3 mils, painted	Nil	0·2	—	—

* A dash (—) indicates that the surface concerned had not failed after 738 days' exposure.

deposited, 0·05 mil, phosphated, painted) and 12 (zinc, electrodeposited 0·3 mil, phosphated, painted) showed to advantage in the early stages of exposure whilst the paint film remained effective.

It will be evident from these observations that the selection of the best combinations of metallic coating, surface treatment, and paint for composite protective schemes to be used on steel, whether of light-gauge or of the structural type, is a subject to which it will be desirable to devote considerable study, involving systematic research work over a number of years. This question is outside the terms of reference of the Methods of Testing (Corrosion) Sub-Committee, but it is being investigated by Joint Technical Panel J/P1—Paints for Structural Steelwork, of the Protective Coatings Sub-Committee.

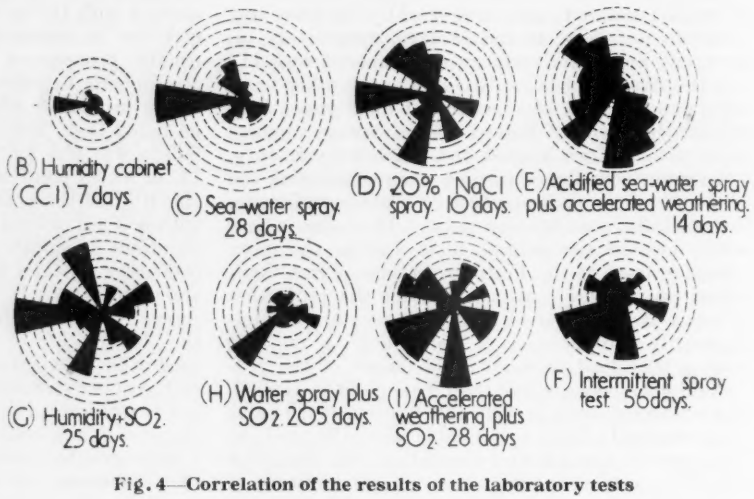

(B) Humidity cabinet (CC1) 7 days.
(C) Sea-water spray. 28 days.
(D) 20% NaCl spray. 10 days.
(E) Acidified sea-water spray plus accelerated weathering. 14 days.
(G) Humidity+SO2. 25 days.
(H) Water spray plus SO2. 205 days.
(I) Accelerated weathering plus SO2. 28 days.
(F) Intermittent spray test. 56 days.

Fig. 4—Correlation of the results of the laboratory tests

Correlation of Laboratory Test Results with the Results of the Outdoor Exposure Tests—It is obvious that there can be no hard and fast correlation of the results of the laboratory tests on the one hand and those of the field test on the other, because in both types of test the orders of merit vary with the duration of exposure; moreover, as has been noted, the final order of merit in the field tests is not yet available. As it is essential, however, that such a correlation be attempted in order to select the most promising laboratory test procedures for the Sub-Committee's purpose, the problem has been approached as follows:

(i) In the case of the field test, the order of merit of the protective schemes after 1·5 years, was taken as the basis of comparison.*

(ii) Correlation coefficients with the results of the laboratory tests were calculated for each inspection made in any particular test. In this connection it may be remarked that the last such inspection, made in some cases when many of the protective schemes had reached an advanced stage of breakdown, is not

*Advantage has been taken of a revision of the text to substitute in the sub-section headed "General Remarks," on p. 468, the results of observations after 2·0 years for observations after 1·5 years in the case of the field tests. In view of the fact that the correlation coefficient between the two sets of field test results is 0·88, it has been thought unnecessary to go to the labour of recalculating all the correlation coefficients between the laboratory tests and the field test.

Table III

CORRELATION OF THE RESULTS OF LABORATORY TESTS AFTER VARIOUS DURATIONS* OF TEST WITH THE RESULTS OF ATMOSPHERIC EXPOSURE OUTDOORS FOR 1·5 YEARS

(*B*) Humidity Cabinet		(*C*) Sea-Water Spray		(*D*) 20% Salt Spray		(*E*) Acidified Sea-Water plus Accelerated Weathering		(*F*) Intermittent Spray		(*G*) Humidity plus SO_2		(*H*) Water Spray plus SO_2		(*I*) Accelerated Weathering plus SO_2	
Duration, days	Correlation Coefficient	Duration, days	Correlation Coefficient	Duration, days	Correlation Coefficient	Duration, days	Correlation Coefficient	Duration, days	Correlation Coefficient	Duration, days	Correlation Coefficient	Duration, days	Correlation Coefficient	Duration, days	Correlation Coefficient
7	0·94	2	0·71	10	0·51	10	0·12	60	0·58	25	0·49	17	0·65	6	0·34
27	0·93	4	0·63	22*	0·49	35†	0·41	...	...	52	0·22	46	0·73	9	0·23
76	0·78	7	0·63	39	0·49	...	...	...	...	101	0·05	101	0·76	13	0·29
...	...	11	0·64	55	0·47	...	...	...	...	143	0·01	169	0·76	27	0·46
...	...	15	0·71	77	0·51	...	...	...	...	...	...	205	0·83	41	0·25
...	...	21	0·78	87	0·51	...	...	...	...	...	...	300	0·67	66	0·13
...	...	25	0·73	...	...	...	...	...	...	...	...	350	0·65	81‡	0·08
...	...	28	0·74	...	...	...	...	...	...	...	...	380	0·57	...	...

* Net times. The longest duration shown, 380 days, corresponded to a gross period of 645 days.
† Fourteen complete test cycles.
‡ During this time the specimens had been subjected to 53 cycles of ultra-violet light and 43 cycles of sulphur dioxide and steam. The number of cycles at intermediate periods is approximately in like proportion.

always the one that is most comparable with the results of the field test, nor is the total duration of any particular test in this investigation necessarily the one that would be selected when applying that test for specification purposes.

(iii) The correlations were expressed in terms of the Spearman ranking coefficient, *i.e.*, the 16 protective schemes were arranged in order of decreasing performance in both types of test from 1 to 16. The correlation coefficient is then given by :

$$\rho = 1 - 6\Sigma d^2/(n^3 - n),$$

where d denotes the difference between the ranking orders in the two tests for each of the 16 protective schemes, and n is the number of items, in this case, 16.*

It should be added that in all cases the ranking orders were assessed from the standard inspection forms in the same way. They represent a composite order of merit deduced from the behaviours both of the undamaged and the damaged halves of the specimens on both surfaces.

The correlation coefficients so deduced are stated in Table III. In the case of some tests considerable variations in this coefficient occurred, according to the stage at which the calculation was made. The fairest comparison between the different tests is therefore based on the maximum value of the correlation coefficient observed for each of them. The degree of correlation achieved at or near this stage of maximum fit is shown in Fig. 4.† In this diagram, the deviations between the ranking order in the field test and those in the laboratory test are plotted in polar co-ordinates, differences of sign being disregarded.

* For a discussion of ranking coefficients, *see* M. G. Kendall, " The Advanced Theory of Statistics," p. 388 *et seq.*, 2nd Edition, vol. 1. London : C. Griffin and Co., Ltd.

† The test durations indicated for tests *E* and *H* are net.

It is evident that, of the eight tests, the three giving results corresponding most closely with those of the field test are :

B—Humidity cabinet. Correlation coefficient 0·94 after 7 days' test
H—Water spray plus SO_2. Correlation coefficient 0·83 after 205 days' test*
C—Sea-water spray. Correlation coefficient 0·74 after 28 days' test (0·78 after 21 days' test)

The correlation coefficients observed for the other methods of testing are not sufficiently high to encourage further investigation of these tests at the present stage, although, as will be shown later in the section dealing with test *I*, on p. 473 (accelerated weathering plus SO_2), this test seems to be a particularly good one for zinc coatings.

It should be mentioned with regard to Fig. 4 that the degree of breakdown of the protective schemes that had occurred at the stage when the best correlation with the field tests was observed was not the same for all the laboratory tests. Thus, in the case of tests *D*, *E*, *H*, and *I*, the specimens were, on the whole, severely corroded, *i.e.*, beyond the point of failure for practical purposes of most or all of the protective schemes, whereas in the case of test *G* and to a lesser extent of tests *B* and *C*, marked breakdown of the protective scheme had not occurred in many cases. On theoretical grounds comparison of the different testing methods should preferably be based on observations made at a stage when the specimens exposed to them and also to the field test show the same degree of breakdown. In practice, this ideal cannot be achieved because different types of test affect different protective schemes in a different manner.

In the present case the subject was explored by calculating the correlation coefficients for the stages

* The time given is the net duration of exposure ; 327 days had elapsed since the test began.

Table IV

ACCELERATION ACHIEVED IN THE LABORATORY TESTS

Test	Rate of Rusting of Bare Steel		Duration of Test to Failure, days*		Approximate Acceleration Factor as Compared with the Field Test		
	Test Duration, days	Mils/Year	Protective Scheme No. 3, phosphated, painted	Protective Scheme No. 10, zinc, electro-deposited, 0·3 mil			
		A	*B*	*C*	*A*	*B*	*C*
A **Field test. (Basis of reference)**	112	3·4	190	738	1	1	1
B **Humidity cabinet**	76	4·0	7	> 76	1	27	< 10
C **Sea-water spray**	28	21·0	c. 18	> 28	6	11	< 26
D **20% NaCl spray**	87	12·4	11	9	4	17	82
E **Acidified sea-water spray plus accelerated weathering**	35	80·9	2	1	24	95	738
F **Intermittent spray test**	60	25·5	c. 30	c. 50	7	6	15
G **Humidity plus SO_2**	143	1·6	109	103	0·5	17	7
H **Water spray plus SO_2**	46	20·8	4	21	6	48	35
I **Accelerated weathering plus SO_2**	81	23·9	10	3	7	19	246

* The criterion of failure is 1% of general rusting, and in the case of the field test *(A)* the figures refer to the front (upper) surface of the specimen only.

in each laboratory test at which certain typical protective schemes showed approximately the same average degree of deterioration. It is unnecessary to discuss the results in detail. The most interesting deduction was that in the case of tests *B* and *H* the correlation with the field tests remained reasonably good, whether it was based on observations made at the time corresponding to equal degree of average breakdown or the time of maximum fit.

Degree of Acceleration Achieved—The degree of acceleration achieved in the laboratory tests will be evident from Table IV. Values have been compiled in three ways on the basis of the following observations : (i) The rate of rusting of the unprotected blank specimens, and (ii) and (iii) the test durations to failure of protective schemes No. 3 (phosphated, painted) and No. 10 (zinc, electrodeposited, 0·3 mil), respectively.

In all cases the overall duration of the test has been taken for the calculations, *i.e.*, rest periods are included where these occur.

Except in the case of bare steel exposed to test *G* (humidity plus SO_2), an accelerated rate of rusting or breakdown has been achieved throughout. Omitting test *E* (acidified sea-water spray plus accelerated weathering), which seems excessively fast, the average acceleration for all the tests is 21 times in the case of the phosphated and painted specimens and 60 times in that of the zinc-coated specimens ; on the average the rate of rusting of bare steel is 4·5 times greater than in the outdoor exposure test at Birmingham. In addition to test *E*, tests *H* (water spray plus SO_2) and *I* (accelerated weathering plus SO_2) are more rapid than the average ; test *G* (humidity plus SO_2) is the slowest of all.

It will also be noted that, as would be expected, the degree of acceleration achieved varies with the basis of assessment, *i.e.*, it is not the same for bare steel, the painting scheme, and the zinc coating, respectively. This is because each test is to some extent selective and affects certain types of protective schemes more adversely than others. The short life of scheme No. 10 (zinc, electrodeposited, 0·3 mil) in relation to that of scheme No. 3 (phosphated, painted) in test *I* (accelerated weathering plus SO_2) is a good example of this.

Observations on Individual Methods of Testing—It is unnecessary to deal with the observations made in each laboratory in great detail, although one or two interesting features brought out by these inspections may be noted.

Humidity cabinet (*B*) : The rate of breakdown of the protective schemes in the C.C.I. humidity cabinet was relatively low for an accelerated test. Thus, after 27 days little appreciable rusting had occurred, except in the case of the protective schemes embodying paint alone and, even after 76 days, rust was only reported on two of the specimens with metallic coatings : Nos. 6 (lead, electrodeposited, 1 mil) and 11 (zinc, electrodeposited, 0·3 mil, painted), in both cases on the back surface only. On the other hand, the test seems to be a fairly searching one for zinc coatings, as after this duration of exposure, blistering was observed on all specimens in which paint had been applied over a zinc coating that had not been phosphated. In the case of specimen No. 16 (zinc, hot-dipped, 3 mils, painted) the paint had peeled from the back to an extent of 80% of the surface at the end of 7 days' test. In the case of specimens Nos. 9 (zinc, electrodeposited, 0·05 mil, phosphated, painted) and 12 (zinc, electrodeposited, 1 mil, phosphated, painted), in which the zinc coating was phosphated before being painted, no marked blistering or flaking of the paint was observed over periods up to 27 days.

Sea-water spray (*C*) : The condition of the protective schemes at the conclusion of this test after

Table V

RESULTS OF THE TESTS BY THE WATER SPRAY PLUS SO_2 METHOD

No.	Protective Scheme — Designation	Duration of Test, days* — To 1% General Rusting	To 5% General Rusting	To 50% General Rusting	To 100% General Rusting	Condition after 380 Days' Test, General Rusting, %
5	Aluminium, sprayed, 3 mils, painted	—	—	—	—	0·6
4	Aluminium, sprayed, 3 mils	119	—	—	—	1·5
14	Zinc, electrodeposited, 1 mil	46	300	—	—	10
15	Zinc, hot-dipped, 3 mils	17	300	—	—	10
16	Zinc, hot-dipped, 3 mils, painted	130	250	—	—	5
12	Zinc, electrodeposited, 0·3 mil, phosphated, painted	183	218	—	—	35
11	Zinc, electrodeposited, 0·3 mil, painted	170	174	319	389	100
7	Zinc, electrodeposited, 1 mil, painted	30	169	—	—	15
9	Zinc, electrodeposited, 0·05 mil, phosphated, painted	30	77	350	380	100
13	Zinc, electrodeposited, 1 mil	10	46	300	—	75
10	Zinc, electrodeposited, 0·3 mil	10	22	63	101	100†
6	Lead, electrodeposited, 1 mil	1	8	77	169	100
3	Phosphated, painted	3	7	46	169	100
1	Painted	2	4	17	46	100†
2	Grit-blasted, painted	2	4	17	46	100†
8	Lead, electrodeposited, 3 mils	1	3	46	205	100

* The test durations were not. A dash (—) denotes that the degree of rusting concerned had not been reached after 380 days.
† Specimen removed from test after 250 days.

Fig. 5—Tests by the sea-water spray method. Appearance of specimens after 28 days' exposure. For description of the protective schemes, see the text

[*Methods of Testing (Corrosion) Sub-Committee*

[*To face p.* 472

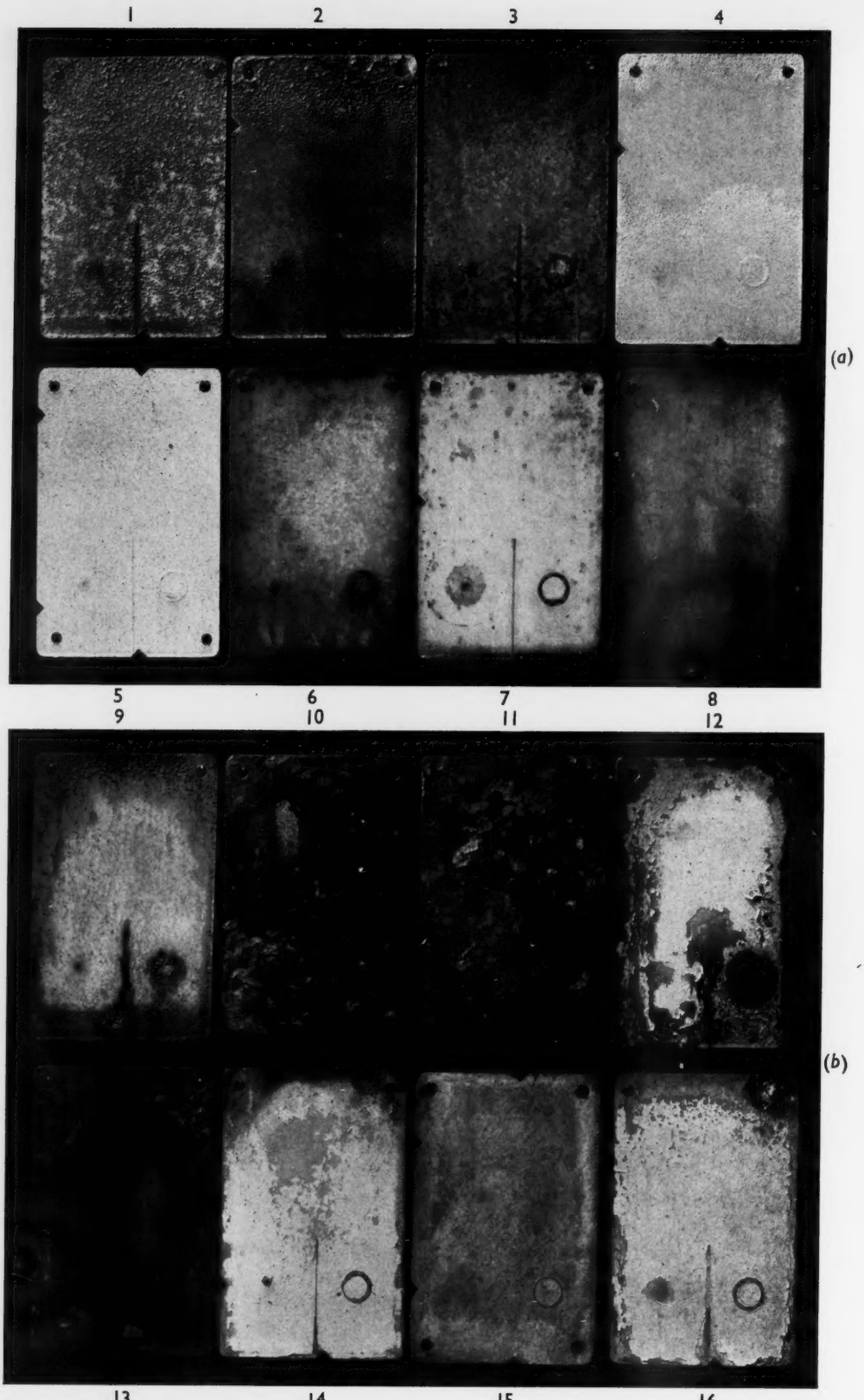


Fig 6.—Tests by the water-spray-plus-SO_2 method. Appearance of the specimens after 380 days' exposure (250 days for Nos. 1, 2, and 10). For description of the protective schemes see the text

Methods of Testing (Corrosion) Sub-Committee]
To face p. 473]

28 days is illustrated in Fig. 5. At the end of this period specimens Nos. 0 (control blank) and 2 (grit-blasted, painted) were rusted all over and the following showed lesser degrees of rust :

Protective Scheme No.		General Rusting, %
1	Degreased, painted	50
3	Phosphated, painted	5
6	Lead, electrodeposited, 1 mil ...	0·5
8	Lead, electrodeposited, 3 mils ...	
7	Lead, electrodeposited, 1 mil, painted	0·2

Of the remaining ten specimens, eight had not rusted at all and two showed traces of rust at the groove. Protective scheme No. 12 (zinc, electrodeposited, 0·3 mil, phosphated, painted) was considered to have given the best overall result, whilst No. 4 (aluminium, sprayed, 3 mils) was regarded as the best of the remainder.

20% *NaCl spray* (*D*) : When this test was concluded after 87 days' exposure, three protective schemes stood out as superior to the others. These were, in numerical order, No. 4 (aluminium, sprayed, 3 mils), No. 5 (aluminium, sprayed, 3 mils, painted), and No. 12 (zinc, electrodeposited 0·3 mil, phosphated, painted). None of these specimens showed more than a trace of general rusting ; this was also the case for scheme No. 16 (zinc, hot-dipped, 3 mils, painted), but the paint on the specimen was in poor condition. Scheme No. 9 (zinc, electrodeposited, 0·05 mil, phosphated, painted), for which general rusting was estimated at 0·1%, had also behaved well. The remaining 12 protective schemes had failed, the returns for general rusting, means for both surfaces, ranging from 2 to 70%.

Acidified salt spray plus artificial weathering (*E*) : After 14 cycles in this test the three specimens, Nos. 6, 7, and 8, in which electrodeposited lead forms part of the protective scheme, were free from rust ; the good behaviour of these specimens may be connected with the presence of sulphuric acid in the spray solution. The two aluminium-coated specimens, Nos. 4 and 5, were also in good condition, but were rusted slightly (0·2% of rust in each case). The remaining specimens were badly rusted and in the case of those coated with zinc the order of merit corresponded approximately to the coating thickness.

Intermittent spray test (*F*) : In order to accommodate these tests on the existing apparatus, it was necessary to conduct them on specimens of reduced size, namely, 4 in. × 2 in. This rendered it difficult to obtain sufficiently large undamaged and damaged areas on a single specimen, so the tests were duplicated on sets of undamaged and damaged specimens, respectively. Protective scheme No. 2 (grit-blasted, painted) was placed considerably higher in the final order of merit than in any of the other tests, possibly because of a difference in the condition of grit-blasting, as it was necessary to prepare the set of specimens for this test independently of the others.

Humidity plus SO_2 (*G*) : A curious and unexplained feature of this test is the fact that after 250 hr. exposure in the chamber, specimen No. 15 (zinc, hot-dipped, 3 mils, unpainted) had lost no less than 5·9 g. in weight or approximately one-third of the original coating. This was in marked contrast to the losses in weight of the specimens with electrodeposited zinc coatings, also exposed bare, which were 0·4 g. (No. 10) and 0·6 g. (No. 13). It may be noted that in the humidity cabinet test (*B*) the losses in weight of all three zinc-coated specimens (Nos. 10, 13, and 15) were, as might be expected, identical. The attack on bare zinc coatings in the sulphur dioxide chamber resulted in a curious crystalline distribution of the corrosion product, in a form resembling a lead-tree. This acicular structure was still evident on the electrodeposited coatings after 10 days' exposure ; the hot-dipped coating was too heavily attacked to show any evidence of this after the early stages of the test.

Water spray plus SO_2 (*H*) : This test is still in progress, the last inspection to date having been made after 380 days' net exposure. Specimens Nos. 1 (degreased, painted), 2 (grit-blasted, painted), and 10 (zinc, electrodeposited, 0·3 mil) were removed from test after 250 days, by which time they had failed badly.

All the protective schemes except Nos. 5 (aluminium, sprayed, 3 mils, painted) and 4 (aluminium, sprayed, 3 mils) have now failed. As, moreover, the test gives a high correlation with the results of outdoor exposure (*see* p. 468), it is of interest to consider briefly the relative performances of the various protective schemes. The simplest method of doing this is to tabulate the durations of test in each case corresponding to the development of 1%, 5%, 50%, and 100% of general rusting on the undamaged areas of the specimens. These will be found in Table V, together with a statement of the percentage of general rusting after 380 days.*

The main features of these results are :

(i) The excellent performance of the sprayed aluminium coating, whether painted or not.

(ii) The beneficial effect of phosphating, both in the case where the paint was applied over bare steel (compare protective schemes Nos. 3 and 1) and over an electrodeposited zinc coating (compare protective schemes Nos. 12 and 11).

Photographs of the fronts of this set of specimens after 380 or in some cases 250 days' test are reproduced in Fig. 6.

Accelerated weathering plus SO_2 (*I*) : This method of testing produced rapid breakdown of the protective schemes and, as will be seen from Table VI, eleven of the 16 protective schemes showed 5% of general rusting after 30 days' exposure or less. This degree of rusting may be regarded as a reasonable criterion of failure for a metallic coating alone, although in the case where the protective scheme includes paint, it might be preferable to take a lower figure, say, 1%.

The five protective schemes that had suffered less than 5% general rusting after a month's test were those including metallic coatings 3 mils thick of sprayed aluminium, electrodeposited lead, or hot-dipped zinc, in the first and last cases both without and with a coat of stoving paint. The results of the last inspection after 81 days showed that of these five protective schemes, the two based on sprayed

* This is the net exposure time ; the test had been in progress for 645 days.

Table VI

RESULTS OF THE TESTS BY THE ACCELERATED WEATHERING PLUS SO_2 METHOD

Duration of Test to 5% General Rusting, days	Protective Scheme		Duration of Test, days		Condition at End of Test*	
	No.	Designation	To 50% General Rusting	To 100% General Rusting	General Rusting, %	Change in Weight, cg.
>81	4	Aluminium, sprayed, 3 mils	...	...	0·1	75
	5	Aluminium, sprayed, 3 mils, painted	...	...	Nil	−8
	8	Lead, electrodeposited, 3 mils	...	...	2	6
72	16	Zinc, hot-dipped, 3 mils, painted	...	...	10	−1453
66	15	Zinc, hot-dipped, 3 mils	...	...	20	−1359
30	7	Lead, electrodeposited, 1 mil, painted	...	...	20	−255
28	14	Zinc, electrodeposited, 1 mil	39	55	100	−48
22	12	Zinc, electrodeposited, 0·3 mil, phosphated, painted	38	66	100	257
	13	Zinc, electrodeposited, 1 mil	32	41	100	435
17	6	Lead, electrodeposited, 1 mil	...	...	10	−11
14	3	Phosphated, painted	...	...	35	57
	9	Zinc, electrodeposited, 0·05 mil, phosphated, painted	32	...	75	519
12	1	Painted	...	...	35	102
10	11	Zinc, electrodeposited, 0·3 mil, painted	17	27	100	492
6	2	Grit-blasted, painted	20	...	75	65
5	10	Zinc, electrodeposited, 0·3 mil	7	9	100	460
...	0	None	...	...	100	522

* 66 days (42/35 cycles, *i.e.*, 42 cycles of the ultra-violet radiation and 35 cycles of sulphur dioxide and steam), except in the case of specimens Nos. 0, 4, 5, 8, 15, and 16, the exposure of which was continued for 81 days (53/43 cycles). The numbers of cycles for intermediate periods are roughly proportional to the test duration in days.

aluminium were markedly superior to the others.

The changes in weight of the specimens were observed throughout the test and the final values recorded are given in Table VI. Gains in weight are due to the formation of rust on the specimen, for instance, the uncoated blank specimen No. 0 had gained 5·22 g., whilst losses are due to the corrosion and loss of the protective coatings, especially zinc, such as, for example, the loss of 13·59 g. for specimen No. 15 (zinc, hot-dipped, 3 mils). Thus, a marked change of weight in either direction is evidence of breakdown, although the converse is not necessarily true, as the two factors, increase in weight due to rust formation and loss in weight due to loss of coating, may balance each other.

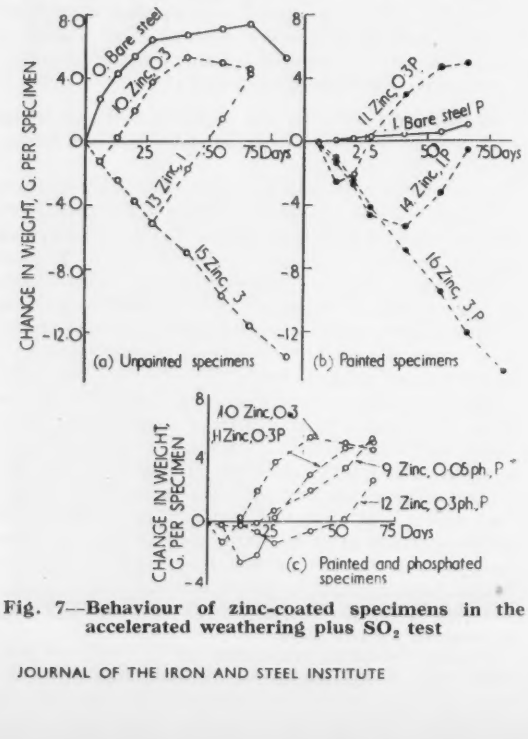


Fig. 7—Behaviour of zinc-coated specimens in the accelerated weathering plus SO_2 test

It is instructive to study the changes in weight of the zinc-coated specimens over the test period. These are shown graphically in Fig. 7 from which the following conclusions can be drawn.

(i) Fig. 7 (*a*): The weight of the base-steel control specimen No. 0 increases progressively from the start owing to the formation of rust. Towards the end of the test the amount of rust formed has become so large that it begins to fall off and the weight decreases. On the other hand, the weights of the zinc-coated but unpainted specimens, Nos. 10, 13, and 15, decrease steadily at first owing to the dissolution of the zinc coating. This process continues until the basis steel is laid bare and rusting sets in. At this stage, which has been reached within the duration of the test in the case of specimens Nos. 10 and 13, carrying electrodeposited zinc coatings 0·3 and 1 mil thick, respectively, the loss in weight of the specimens is arrested and their weight begins to increase. In the case of specimen No. 10 the point at which the rate of mechanical loss of rust from the specimen exceeds the rate of rust formation has been passed before the conclusion of the test.

The durations of test to complete removal of the zinc coating from specimens Nos. 10 and 13, approximately 6 and 27 days, respectively, are roughly proportional to the coating weights, which were 1·57 g. for No. 10 and 5·57 g. for No. 13. In fact, it is clear from the uniform slope of the curve for specimen No. 15, from which the zinc coating weighing about 18 g. had not been completely removed after 81 days, that in this test the zinc coatings were corroded away at a steady rate approximately equal to 0·168 g./

Table VII

EFFECT OF SURFACE TREATMENT ON THE WEIGHT OF PAINT APPLIED BY DIPPING

No.	Surface Treatment — Designation	Weight of Dry Paint, g. per specimen	Average Paint Film Thickness, mil†
1	None (bare steel)	1·74	0·90
2	Grit-blasted	2·05	1·06
3	Phosphated	1·82	0·94
5	Aluminium, sprayed, 3 mil	2·40	1·24
7	Lead, electrodeposited, 1 mil	2·27	1·17
9	Zinc, electrodeposited, 0·05 mil, phosphated	1·79	0·92
11	Zinc, electrodeposited, 0·3 mil	1·76	0·91
12	Zinc, electrodeposited, 0·3 mil, phosphated	2·01	1·04
14	Zinc, electrodeposited, 1 mil	1·87	0·96
16	Zinc, hot-dipped, 3 mil*	2·60	1·34
	Average for all specimens	2·03	1·05

* The surface of these specimens was etched with a 5% solution of concentrated hydrochloric acid in an organic solvent.

† These values are approximate and are calculated by simple proportion, so as to correspond with the results given in Table VIII.

Table VIII

VARIATION IN THE THICKNESS OF THE DRY PAINT FILM FROM TOP TO BOTTOM OF THE SPECIMENS

Distance from Top Edge, in.	Thickness of Paint Film, mils			
	No. 3	No. 12	No. 14	No. 16
	Phosphated	Zinc, electro-deposited, 0·3 mil, phosphated	Zinc, electro-deposited, 1 mil	Zinc, hot-dipped, 3 mils
0·5	0·60	0·80	0·56	0·76
1·5	0·80	0·88	0·68	0·68
2·5	0·88	0·88	0·80	1·36
3·5	0·96	1·04	0·96	1·76
4·5	1·04	1·16	1·00	1·96
5·5	1·16	1·20	1·08	2·52
Average	0·91	0·99	0·85	1·51
Gradient, mils/in.*	0·10	0·085	0·105	0·28

* [(Mean reading at 0·5 in. and 1·5 in.) — (mean reading at 4·5 in. and 5·5 in.)]/4.

specimen/day or 6·5 oz./sq. ft./year. This is equivalent to 10·8 mils of zinc per year, a rate of corrosion approximately 20 times greater than that observed in industrial atmospheres in this country, which is about 0·3–0·4 oz./sq. ft./year.

(ii) Fig. 7 (*b*): The behaviour of zinc-coated and painted specimens follows closely that of the corresponding unpainted ones. The protection afforded by the paint, as calculated from the differences in the test durations to complete removal of the zinc coating (corresponding to the maximum observed losses in weight) is approximately equivalent to about 10 days.

(iii) Fig. 7 (*c*): It is clear from these curves, particularly if they are studied in conjunction with Table VI, that the performance of protective schemes comprising a zinc coating plus paint has been improved by phosphating. Thus, specimen No. 12 (zinc, electrodeposited, 0·3 mil, phosphated, painted) had a life to 5% rusting of 22 days, as compared with 10 days for specimen No. 11 (zinc, electrodeposited, 0·3 mil, painted). The beneficial effect of phosphating in improving paint adhesion over zinc coatings is well illustrated by Fig. 8, which shows the appearance of the fronts of some of the specimens after 6 days' exposure (4 periods in the weatherometer and 3 periods in sulphur dioxide plus steam).

The general impression gained from the results is that a method of testing of this type, incorporating exposure to steam and sulphur dioxide, shows promise of providing a good and rapid means of testing metallic coatings, particularly perhaps in the case of zinc.

Effect of Coating Thickness—It was observed when preparing the specimens that the colour of the stoved paint film varied according to the nature of the previous surface treatment of the steel. Moreover, the average weight of dry paint applied to each specimen was found to differ considerably from one series of specimens to another, as is shown in Table VII. Statistical analysis of the detailed data showed that these differences were significant. They are a natural result of the differences in the underlying surface of the metal, coupled with the fact that the paint was applied by dipping; for example, the sprayed aluminium coating is porous and absorbs more paint.

Another important observation was that there was a marked difference in the thickness of the paint film from the upper to the lower edge of the specimens.* This variation can be illustrated by the results of determinations made on a few typical specimens which are given in Table VIII. These measurements were made directly by means of a micrometer gauge, readings being taken before and after scraping the paint film from both sides of the specimen.†

The observations reveal a thickness gradient in the paint film varying for the different undercoats from 0·085 to 0·28 mil/in. Presumably, the existence of thickness gradients in single films of paint applied by dipping and stoving is unavoidable, and in fact a clause relating to flow properties is included in the specification of the stoving paint used, C.S.2249. This stipulates that the film thickness of the paint, as applied to a panel 36 in. long, must be not less than 0·5 mil at the top of the panel and not more than 1·5 mil at 1 in. above the "fat edge" at the bottom, *i.e.*, a thickness gradient of about 0·03 mil/in. is regarded as permissible. The observed gradients are considerably in excess of this, possibly because of the small length of the specimens.‡

* These were suspended from two holes near the upper 4-in. edge, with the 6-in. edge vertical during dipping and stoving.

† It was noted, when removing the paint by scraping, that its adhesion was stronger in the case of the two phosphated surfaces, Nos. 3 and 12, than in that of the non-phosphated surfaces, Nos. 14 and 16.

‡ It would appear from the results of practical tests on 36-in. panels submitted through the courtesy of a member of the Sub-Committee, that the variation in thickness is chiefly concentrated within 6 in. of the top and 3 in. of the bottom edge. The central area is of fairly uniform thickness and extends considerably as the panel length increases, leaving relatively small areas of thin and thick paint coating.

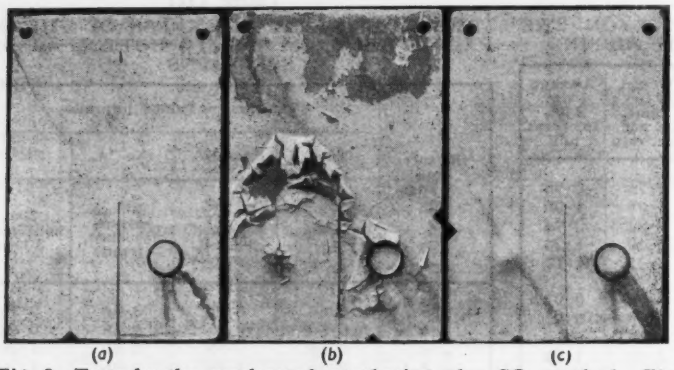

KEY
(a) No. 9. Zinc, electrodeposited, 0·05 mil, phosphated, painted
(b) No. 11. Zinc, electrodeposited, 0·3 mil, painted
(c) No. 12. Zinc, electrodeposited, 0·3 mil, phosphated, painted
(a)
(b)
(c)

Fig. 8—Tests by the accelerated weathering plus SO_2 method. Effect of phosphating on the adhesion of paint to electrodeposited zinc coatings. Photographed after four periods in the weatherometer and three cycles of SO_2 plus steam

The effect of these variations in coating thickness has to be considered in relation to the variation in the surface roughness of the different types of specimen, a point which will be discussed in the next sub-section. Meanwhile, it will be obvious that failure of the protective schemes would be expected to occur first near the top edges of the specimens where the paint is thinnest, and such in the main was observed to be the case.

Determinations of Surface Roughness—As already mentioned on p. 472, early breakdown of the protective paint film was observed in the case of specimen No. 2 (grit-blasted, painted) when exposed in the field test, and this specimen behaved in a similar manner in most of the laboratory tests. Inspection showed that this rapid failure was associated with the inadequate thickness of the paint film (of the order of 0·6–0·8 mil near the top edge of the specimen, *see* Table VIII) in relation to the roughness of the surface left after grit-blasting. As a result "peaks" of the metal projected through the paint film and were left unprotected. This raised the important question of the effect of surface roughness generally in its relation to film thickness of paint, and it was decided to make a systematic series of roughness determinations on a set of specimens representing all the protective schemes included in the tests.

The measurements were made by means of a Tomlinson surface recorder, in which the surface under examination is traversed by a fine probe driven by a small electric motor. The trace thus obtained is enlarged optically and recorded either photographically or by hand. A few typical results for the protective coatings in question are reproduced in Fig. 10.*

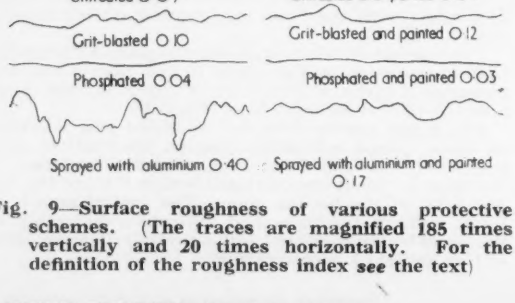


Fig. 9—Surface roughness of various protective schemes. (The traces are magnified 185 times vertically and 20 times horizontally. For the definition of the roughness index *see* the text)

In order to obtain a quantitative index of the roughness of each surface a mean straight line was drawn through each trace,† and the root mean square of the deviations of points on the trace (at intervals of 0·1 in.) was calculated. The resulting figure is referred to as the "roughness index" and for purposes of clarity will be expressed here in mils in relation to the actual surface. In general, three determinations were made on each specimen and the root mean square of the roughness indices so obtained was taken as the roughness index of the surface concerned.

The values of the roughness index for the various surfaces are given in Table IX.* The main deductions made from the measurements are stated briefly below; a more extensive investigation would be necessary to establish how far these are of general application.

As would be expected, painting decreased surface roughness in most cases. The decrease was particularly marked in the case of unpainted surfaces with a relatively high roughness index, such as Nos. 0 (bare steel), 4 (aluminium, sprayed, 3 mils), and 15 (zinc, hot-dipped, 3 mils). On the other hand, the roughness of the smoother surfaces, most of which were electrodeposits, was only reduced slightly by painting. There was also some indication that the roughness of the electrodeposited coatings increased with their thickness. Thus, an electrodeposited zinc coating 0·05 mil thick had a roughness index of 0·028 mils, as compared with values of 0·050 and 0·056 mils for electrodeposited zinc coatings 1 mil and 3 mils thick, respectively.

The surface roughness of bare steel was reduced by phosphating, but that of electrodeposited zinc coatings was increased.

It is obvious from these results that, when utilizing

* The data quoted in Table IX are deduced from measurements of several traces. This is the explanation of any apparent discrepancies between Table IX and Fig. 10.

† This mean line was not necessarily parallel to the surface of the specimen.

Table IX

ROUGHNESS INDEX OF VARIOUS PROTECTIVE COATINGS

Nos.	Surface Treatment or Protective Scheme	Roughness Index, mils	
	Designation	Unpainted	Painted
0, 1	Bare steel	0·092	0·052
2	Grit-blasted	0·105	0·120
3	Phosphated	0·035	0·026
4, 5	Aluminium, sprayed, 3 mil	0·434	0·240
6, 7	Lead, electrodeposited, 1 mil	0·062	0·052
8	Lead, electrodeposited, 3 mils	0·074	...
...	Zinc, electrodeposited, 0·05 mil	0·028	...
9	Zinc, electrodeposited, 0·05 mil, phosphated	0·038	0·038
10, 11	Zinc, electrodeposited, 0·3 mil	0·050	0·042
12	Zinc, electrodeposited, 0·3 mil, phosphated	0·060	0·042
13, 14	Zinc, electrodeposited, 1 mil	0·056	0·060
15, 16	Zinc, hot-dipped, 3 mils	0·100	0·070

paint as part of a protective scheme, careful consideration should be paid to the relation between the thickness of the paint film and the roughness of the surface to which it is applied. It is equally clear that, after making all due allowance for flow, a coating with an average thickness of about 1 mil and a minimum thickness of the order of 0·6 mil, cannot be expected to provide adequate cover for many of the surfaces included in this investigation, for it must be remembered that the " roughness index " stated in Table IX is a root-mean-square value and, as such, represents but a fraction, say, one-fifth, of the maximum distance between the peaks and the troughs in the surfaces examined. Clearly, too, other things being equal, a paint film of the thickness in question would be expected to function most efficiently on the surfaces having the minimum degree of roughness.

It is unnecessary to pursue this matter further for the moment and the essential function of these experiments will have been served if they lead to increased consciousness of the importance of paint-film thickness and of surface roughness in relation to each other. It may, however, be noted that there is some correlation between the roughness index of the unpainted surfaces (Table IX) and the average weight of paint applied to them (Table VII). The correlation coefficient, calculated by the Spearman ranking method, is 0·48.

REPRODUCIBILITY OF THE A.R.D. SEA-WATER SPRAY TEST

Introduction

As soon as the main results of the laboratory tests described in the first section were available, they were surveyed with a view to deciding which of the various experimental methods was most suitable for immediate development for the purposes of the British Standards Institution. At the time, weighing carefully all the factors involved, it was decided that it would be wise to concentrate on the A.R.D. sea-water spray test, without prejudice to the later development of other methods that had also shown promise. The first step was clearly to investigate how far this test was reproducible from one laboratory to another and the series of experiments that will now be described was undertaken with this object in view.

Experimental Details

General Experimental Scheme—For the purpose of this investigation, twelve similar sets of six specimens each were prepared as follows :

(i) Two specimens of bare steel for use as controls.

(ii) Two specimens of steel as in (i) painted with a single coat of stoving paint C.S.2249.

(iii) Two specimens as in (ii), but phosphated before painting.

One set of specimens was subjected to the A.R.D. sea-water spray test (*C*) conducted at room temperature under standardized conditions in each of ten laboratories, and one set was used for an atmospheric exposure test outdoors at Selly Oak, Birmingham. As a matter of general interest the twelfth set was subjected to a modified form of the sulphur dioxide and steam cycle (test *I*).

Experimental Technique—With a few minor modifications, more particularly in the methods of assessing failure, the methods of preparing the specimens and of conducting the tests were essentially the same as those described in the previous section. Attention should be drawn, however, to two points, namely :

(i) A synthetic sea-water was substituted for the natural product. This was prepared by dissolving the following salts in distilled water* :

NaCl	27·3 g.
$MgCl_2$	3·5 g.
$MgSO_4$	1·8 g.
$CaSO_4$	1·3 g.
KCl	0·7 g.
KBr	0·1 g.
$NaHCO_3$	0·1 g.

The quantities given relate to 1 litre of solution.

(ii) As it was felt that under industrial conditions difficulties might arise in making a groove in the specimens (*see* p. 466) this form of damage was omitted. A second scratch, made to penetrate into the underlying metal, was substituted in its place. The impact dome and the scratch penetrating the paint coating only were retained unaltered.

The size of specimen used was again 6 in. by 4 in. by 20 S.W.G., and the panels were prepared from a similar batch of mild-steel sheet.

Assessment of Breakdown—For standards purposes it is clearly necessary to lay down certain criteria of acceptability to be satisfied by the protective schemes at the end of a stipulated test period. Although these were modified slightly as a result of the investigation under discussion, it is desirable to state the criteria adopted in this instance. They were as follows :

(i) *On the impact dome :* Rust, if present, must be confined to a distance of 0·15 in. from the centre of the dome.

* In later work the composition of the synthetic sea-water was simplified (p. 482).

(ii) *Beyond 0·05 in. from the boundaries of the scratches :* No rust, rust stain, or corrosion product ; no flaking, blistering, or other defects of the protective coating.

(iii) *On the scratches :* Rust, if present, must be confined to the scratches only.

(iv) *General :* There shall be no rust or rust stain and no flaking, blistering, or other defect of the protective coating at any undamaged part of the specimen lying within an area enclosed by a line drawn $\frac{1}{4}$ in. from each edge.*

Failure to satisfy any of these conditions was regarded as the point of breakdown of the protective scheme.

In order to obtain the maximum information from the investigation, with a view to the standardization of the test method, considerably more data were collected than would be required when the test was applied solely for control purposes. Each laboratory was supplied with a set of instructions providing for records at stated intervals of the spread of breakdown under the various headings, *e.g.*, spread of breakdown from the edge, at the scratches, at the impact dome, etc. The results have enabled the effects of the individual criteria of breakdown to be accurately assessed, although the personal factor was not entirely eliminated by this procedure.

Experimental Results and Discussion

Introduction—It will be convenient to consider the experimental results under three headings, namely :

(i) Main series of tests (paint C.S.2249).
(ii) Test by SO_2 plus steam. Method *I*.
(iii) Reproducibility of the rate of corrosion of the control blanks.

Main Series of Tests (Paint C.S.2249)—The mass of data accumulated in this collaborative investigation in ten laboratories may most simply be presented in the following series of Figures and Tables :

Figure 10 shows in the form of bar diagrams the duration of test to failure from any cause observed in each testing laboratory. A distinction is made between the front and back surfaces of the specimens.

Figure 11 consists of a series of graphs illustrating the variation throughout the test of the various factors such as spread of rust from the impact dome, percentage general rusting, etc. With a few exceptions the values plotted represent the average values for all ten laboratories, *i.e.*, 20 surfaces in each case.

Table XI gives the average lives to failure for each type of surface as determined by interpolation in Fig. 11 for each criterion of acceptability.

Finally, in Table X the frequency of the cause of failure, *i.e.*, the criterion for which breakdown first reached the point of failure, is reported for each of the 20 test surfaces of each type.

Discussion of Results—It should be borne in mind that the spread of the individual results shown in Fig. 10 has undoubtedly been increased by differences in the operating conditions in individual laboratories, particularly as regards the ambient temperature and the weight of spray deposited on the specimens, to which further reference will be made later when considering the losses in weight of the uncoated mild-steel control blanks (*see* p. 485). To this must be added a natural uncertainty in this stage of development of the test of the interpretation of some of the criteria of failure ; in fact, one of the main points brought out by this experimental series was the necessity of altering the definitions of failure so as to lessen the possibility of misunderstanding regarding them. After making due allowance for these factors, it was concluded that the test as such was reasonably reproducible and from this point of view was acceptable for standards purposes.

It will be noted that the average results for all the laboratories bring out clearly the value of phosphating as a surface preparation for painting, the lives to failure being as follows :

Phosphated
Front surfaces 5·40 days. Standard deviation 0·61
Back surfaces 6·39 days.* Standard deviation 1·50

Non-Phosphated
Front surfaces 2·45 days. Standard deviation 0·93
Back surfaces 3·15 days. Standard deviation 0·54

* Omitting two results that are clearly anomalous.

* In assessing failure from general rusting of the undamaged surface, 0·1% of rust or rust-staining was assumed to be the permissible limit under this clause.

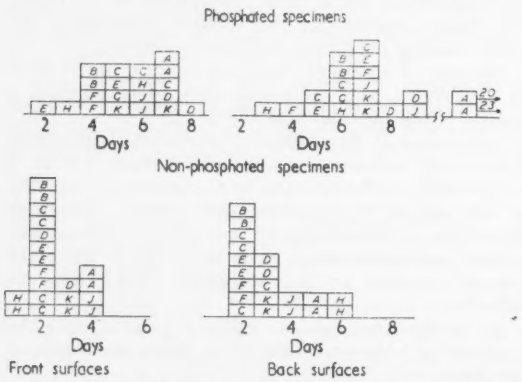


Fig. 10—Lives to failure in the A.R.D. sea-water spray test. Reproducibility of results in different laboratories. (All specimens received a single coat of stoving paint to C.S. 2249)

Table X
FREQUENCIES OF THE CAUSES OF FAILURE IN THE A.R.D. SEA-WATER SPRAY TEST

Cause of Failure	Number of Cases Observed*			
	Front		Back	
	Phosphated	Non-Phosphated	Phosphated	Non-Phosphated
Impact dome	$7\frac{1}{3}$	2	$\frac{1}{2}$	1
Scratches	$5\frac{5}{6}$	6	...	...
Edges	0	0	0	0
General rusting	$6\frac{5}{6}$	12	$19\frac{1}{2}$	19

* The fractions arise from the fact that in some cases a surface failed simultaneously from two or three causes.

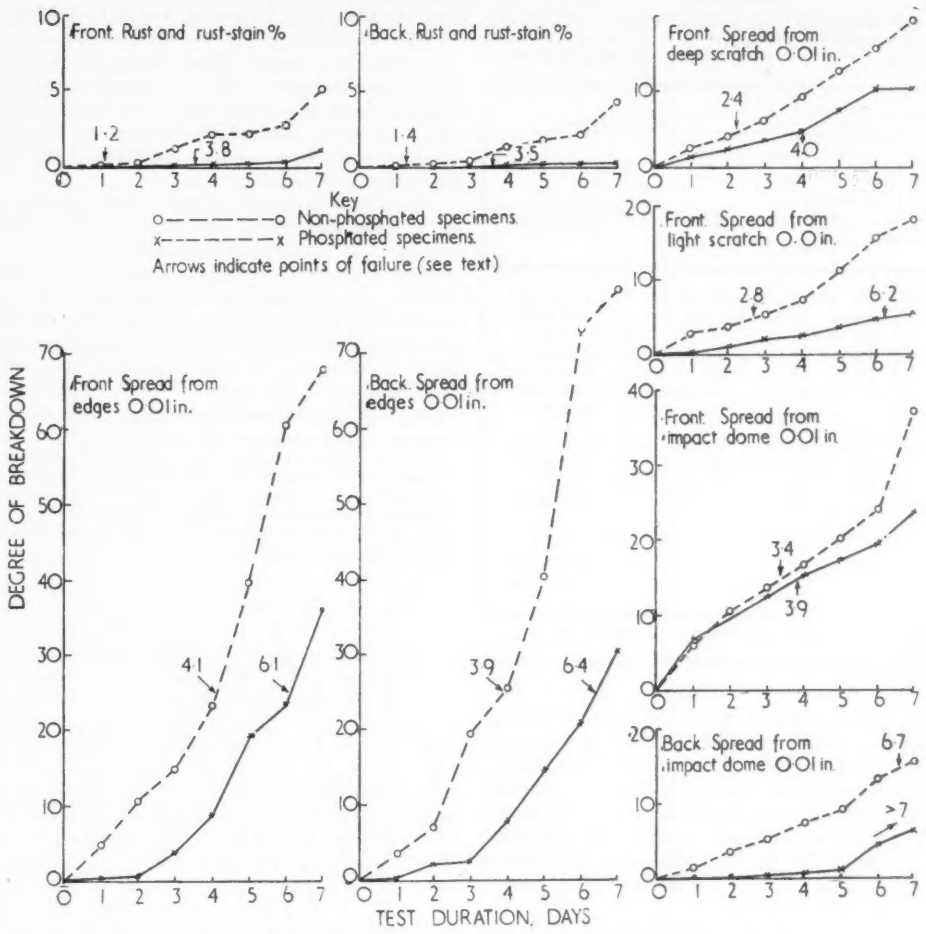

Front. Rust and rust-stain %
Back. Rust and rust-stain %
Front. Spread from deep scratch 0·01 in.
Front. Spread from light scratch 0·0 in.
Front. Spread from impact dome 0·01 in.
Back. Spread from impact dome 0·01 in.
Front. Spread from edges 0·01 in.
Back. Spread from edges 0·01 in.
Key
Non-phosphated specimens.
Phosphated specimens.
Arrows indicate points of failure (see text)
DEGREE OF BREAKDOWN
TEST DURATION, DAYS

Fig. 11—A.R.D. sea-water spray test. Effect of test duration on the degree of breakdown. (Average results for ten laboratories)

Table XI

A.R.D. SEA-WATER SPRAY TEST. LIVES TO FAILURE OF A SINGLE COAT OF STOVING PAINT TO C.S.2249 (AVERAGE VALUES FOR 20 SURFACES)

Criterion of Failure	Permissible Limit	Life to Failure, days			
		Front Surfaces		Back Surfaces	
		Phosphated	Non-Phosphated	Phosphated	Non-Phosphated
Rusting and rust-staining	0·1%	3·8	1·2	3·5	1·4
Spread of damage:					
Impact dome	0·15 in.	3·9	3·4	>7	6·7
Light scratch	0·05 in.	6·2	2·8	...	...
Deep scratch	0·05 in.	4·0	2·4	...	...
Edges	0·25 in.	6·1	4·1	6·4	3·9

Table XII

LOSSES IN WEIGHT OF UNPAINTED CONTROL BLANKS EXPOSED TO THE A.R.D. SEA-WATER SPRAY TEST IN DIFFERENT LABORATORIES

Laboratory	Loss in Weight, cg./specimen/day*		Test Conditions	
	Specimen No.		Temp., °F.	Weight of Spray,† g./specimen
	1	2		
A	20	51	55–58	1·4–2·0
B	35	36	64	0·7–1·0
C	34	29	60–65	1·0
D	19	15	32–53	1·3
	17	13	40–61	0·6–1·0
E	61	49	58–65	1·8, later 0·2–0·4
F	28	33	69	0·6–0·7
G	11	18	52–63	0·5–1·0
H	32	21	54–61	0·7–0·8
J	19	42	55–65	2·5
K	18	13	35–45	0·8–0·9
C‡	27	22	...	(SO_2 and steam test)

* The total area of a specimen is approximately 48 sq. in.
† Both sides.
‡ Test by the SO_2-plus-steam method; both specimens removed after 5 days.

In the original series of tests by the A.R.D. sea-water spray method (pp. 466 and 472) a specimen coated with the same protective scheme, phosphating followed by a single coat of paint C.S.2249, successfully passed a test of 7 days, whereas the average life under test in the present series was 5·4 days. This difference may be attributed to the fact that the thickness of the dry paint film was on the average about 20% less than in the original test.

A study of Table X throws light on the relative importance of the criteria of breakdown in determining failure. It is possible to arrange these criteria so as to give them any desired weighting factors. The policy adopted by the Sub-Committee has been to endeavour to choose them in such a way that the protective scheme is equally likely to fail through any one of them, *i.e.*, to give the same weight to resistance to breakdown at the seat of mechanical damage as to resistance to failure from general rusting. It will be seen from Table X that this result has approximately been achieved in the case of the phosphated specimens, but it is interesting to observe that, as is shown in Table XI, the difference between the lives of the stoved paint coating over phosphated and over non-phosphated steel is least marked for the front of the impact dome, where the whole protective scheme is in tension.

Tests by the SO_2-plus-Steam Method—The method of testing was the same as that described on p. 468, except that exposure to the artificial weathering part of the cycle incorporating ultra-violet light was omitted. Under these conditions the painted specimens that had not been phosphated broke down rapidly and failed from rust-staining after 2 days' test. Those which had been phosphated failed from rust-staining and blistering within 3–4 days.

Reproducibility of the Rate of Corrosion of the Control Blanks—Two control blank specimens of unpainted steel were included with each set of specimens. The first of these was removed at the time of failure of the first front surface of the painted specimens in that set and the second at the time of failure of the last front painted surface.

The losses in weight of the control specimens were determined by reweighing them after they had been derusted by means of Clarke's solution.* The results of these determinations are recorded in Table XII. The loss in weight has been expressed in terms of centigrams per specimen per day, by dividing the observed loss in weight by the duration of test to the time of removal. As will be shown later, the corrosion/time curve for unprotected steel exposed to the spray test is not strictly linear; thus the value of

* This consists of 2 parts of antimonious trioxide and 5 parts of stannous chloride dissolved in 100 parts of concentrated hydrochloric acid. The specimen is immersed in the cold solution and kept moving until rust removal is complete; it is then washed and dried before the final weighing.

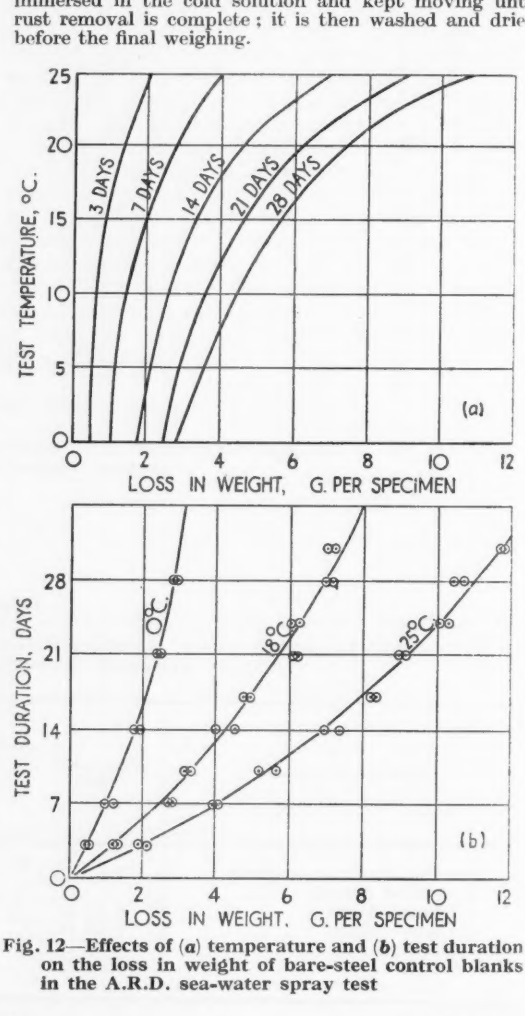


Fig. 12—Effects of (*a*) temperature and (*b*) test duration on the loss in weight of bare-steel control blanks in the A.R.D. sea-water spray test

the figure so obtained would be expected to vary throughout exposure in any one laboratory. For the present purpose such variations are unimportant.

It is evident from Table XII that there were marked deviations between the rates of corrosion of the bare-steel control blanks at the different laboratories. The subject was thoroughly investigated by a series of supplementary tests.* The main conclusions drawn from this work were :

(i) The most potent source of variations in the rate of corrosion of bare steel in the A.R.D. sea-water spray test is difference in temperature. This will be evident from the curves reproduced in Fig. 12. In round figures the loss in weight over a given test period was 4 times greater at 25° C. (77° F.) than at 0° C. (32° F.). Wide variations in temperature should, therefore, be avoided in carrying out the test ; if the temperature for the test is controlled within the range 55–70° F. (13–21° C.), the amount of corrosion will not vary by more than ± 25% from the average value for this range.

(ii) The effect of variation in the weight of spray applied to the specimens was not very marked. Over the whole range, from the lightest spray (0·2 g. per specimen) to the heaviest practicable spray (2 g. per specimen, above which the drops began to run down the specimen), the variation in the loss in weight was approximately 35% (from 3·62 g. to 4·87 g. after 14 days' test). As a result of this work it was decided to standardize on a weight of spray of between 0·5 and 1·0 g. per specimen.

(iii) No significant difference was found between sprays of natural sea-water and of two artificial sea-waters, in which slightly different formulae were used.

(iv) The loss in weight was not directly proportional to the test duration, as will be seen from Fig. 12 (*b*). Thus the average ratio of the losses in weight after 28 days and 7 days, respectively, for the three temperatures investigated is 2·64.

As it seemed possible, too, that the method of degreasing the specimens, which varied from one laboratory to another, had an effect on their losses in weight during the test, a series of experiments was made in one laboratory in which this was deliberately varied. The results of these tests are given in Table XIII. It is clear from the data that considerable variations in the rate of corrosion of the control blanks may be occasioned by differences both in the nature of the solvent used and in the method adopted for the degreasing process. These variations are probably associated with the traces of residue left from the impurities present in the solvents, which were determined with the results shown.†

It is not claimed that these results are conclusive, but this preliminary survey will suffice to focus attention on the importance of a proper choice of solvent and degreasing process. For the purposes of the proposed standard, it was decided to use pure carbon tetrachloride, applied by swabbing several times, with a final immersion for some minutes in the clean solvent, followed by draining without further swabbing.

Table XIII

EFFECT OF DIFFERENT METHODS OF DEGREASING ON THE SUBSEQUENT CORROSION OF BARE STEEL CONTROL SPECIMENS IN THE A.R.D. SEA-WATER SPRAY TEST*

Method of Degreasing	Loss in weight after 5 days, cg./specimen			
	Pure Trichlorethylene	Commercial Trichorethylene	Carbon Tetrachloride	Benzene
Dipped	190	151	135	143
3 swabs	185	91	134	129
Vapour alone	...	133	...	...
Vapour alone, followed by dipping	...	94	...	...
Vapour alone, followed by 3 swabs	...	95	...	...

* The amounts of non-volatile matter at 100° C. in the various solvents were: Trichlorethylene (pure), nil; trichlorethylene (commercial), 37 mg./litre; carbon tetrachloride, 4 mg./litre; benzene, 56 mg./litre.

APPLICATION OF THE A.R.D. SEA-WATER SPRAY TEST TO INDUSTRIAL PROTECTIVE SCHEMES EMBRACING STOVING PAINTS

Introduction

As a result of the investigations described in the previous sections, appreciable progress had been made towards the standardization of the A.R.D. sea-water spray test, but two important problems remained, namely : (i) To ascertain how far this method was suitable for application as a performance test to the general run of industrial production embracing the types of protective schemes envisaged, and (ii) assuming a satisfactory answer to the first point, to decide what standards of performance were fair and reasonable with due regard to the present level of good commercial practice.

To elucidate these matters, it was important to obtain and test a number of representative industrial protective schemes embracing phosphate treatments followed by the application of stoving paints. This object was achieved without difficulty through the kind collaboration of eight firms engaged in the manufacture of light-gauge steel components of various kinds for which protective schemes of the type in question are used. Each of these firms granted facilities for the processing in their works of a series, or in one case two series, of standard specimens, the work being conducted in the presence of the Sub-Committee's representative(s), by the same methods as those used in actual production, subject in a few cases to such slight adjustments as were necessitated by the differences in the size of the panels and of the articles produced.

Experimental Details

General Organization of the Work—In brief, the investigation involved the preparation of nine sets of some 30 specimens each distributed amongst eight different firms, and tests of various types on a number of these specimens in ten different laboratories.

* Private communication from Dr. S. G. Clarke.

† In this connection Dr. W. H. J. Vernon's fundamental work on the effects of contamination with solid particles on the surface rusting of mild steel will be called to mind.

Basis Materials—As before, mild-steel panels 6 in. × 4 in. × 20 S.W.G. were used. The panels were cut from sheet produced from semi-killed steel approximating to En 2*A* composition, hot-rolled from pickled bar, given a pass through the cold rolls, close-annealed, and pickled.

The bulk of the work was conducted on this sheet as it stood, but some additional tests were made on specimens to which a coating of electrodeposited zinc, approximately 0·4 mil thick, had been applied.*

Protective Schemes—Provision was made for tests on four different types of protective scheme, namely :

(*a*) Mild steel, with a priming coat of stoving paint.

(*b*) Mild steel, phosphated, with a priming coat of stoving paint.

(*c*) Mild steel, phosphated, primed and finished, *i.e.*, with two coats of paint.

(*d*) Mild steel, zinc-coated (0·4 mil), phosphated, with a priming coat of stoving paint.

Application of the Protective Schemes at the Works—Full details of the application of the protective schemes to the test-specimens were recorded through the courtesy of the firms concerned. It is sufficient to state that in all cases the degreasing, phosphating, painting, and stoving processes used in production were followed as closely as possible. Wherever practicable the panels were inserted at the beginning of the production line and allowed to pass through the appropriate stages in company with the actual parts being treated by the process.

All the individual specimens were weighed both before and after treatment at the works, so that the total weights of the coatings applied could be calculated. In addition, samples of the paints used were taken and their efflux time, specific gravity, and percentage volatile content were determined. These data, together with the specific gravity of the volatile portions, the values of which are supplied by the courtesy of the paint manufacturers, were used to determine the specific gravities of the dry paint films and, indirectly, their thickness (*see* p. 487).

It should be noted that in the case of the sets of specimens with reference numbers 7, 8, and 9, the priming paints used were intended as surfacing coats only and were of a type that in actual production inevitably receives a finishing coat to complete the protective scheme. The other sets of specimens, reference numbers 1 to 6 have priming paints that are sometimes used as primer-finishers, *i.e.*, the articles may be put into service without further protection. This fact should be borne in mind when assessing reasonable standards of performance for specimens carrying single coats of stoving paint when exposed to the sea-water spray test (*see* p. 489).

Preliminary Damage to the Protective Scheme—The protective schemes on all specimens subjected to corrosion test were first damaged in the manner already described on p. 477, except that, instead of a light scratch and a deep scratch, two similar light scratches were used. These two scratches were applied by hand, as before, the object being just to penetrate the paint film. The zinc coating was sometimes damaged by the scratching, but the results obtained in the earlier work show that this is not important.

The energy of the blow used to produce the impact dome was intended to be 18 lb./in. as before. It soon became apparent, however, that this figure had been greatly exceeded in the present tests and the energy of the blow was subsequently estimated to be of the order of 50–60 lb./in.* As a result the protective schemes were badly damaged at the dome in the majority of cases, so that the specimens failed rapidly by rusting at this point.

As this error in the energy of the impact blow was not discovered until after the tests had begun and it would have been impracticable to repeat the preparation of the whole series of specimens, subsidiary tests were undertaken to investigate the effects of differences in the energy of the blow on the observations at the impact dome. These tests will be described later (*see* p. 487).

Methods of Testing—In each of nine of the ten collaborating laboratories sea-water spray tests were made on a set of six specimens prepared by one firm only, each laboratory testing a set from a different firm. The protective schemes concerned were : (*a*) Mild steel, with a priming coat of stoving paint (three specimens), and (*b*) mild steel, phosphated, with a priming coat of stoving paint (three specimens).

In the tenth laboratory, tests were made on sets of specimens supplied by all the firms, each set consisting of nine specimens as follows : (*b*) Mild steel, phosphated, with a priming coat of stoving paint (three specimens), (*c*) mild steel, phosphated, primed and finished, *i.e.*, with two coats of paint (three specimens), and (*d*) mild steel, zinc-coated (0·4 mil), phosphated, with a priming coat of paint (three specimens).

The composition of the synthetic sea-water used in the spray was simplified for these tests and was as follows :

	Grammes per Litre of Solution
Sodium chloride, NaCl	23·0
Magnesium chloride, $MgCl_2$, $6H_2O$ ...	9·8
Sodium sulphate, Na_2SO_4, $10H_2O$ ...	8·9
Calcium chloride, $CaCl_2$, anhydrous ...	1·2

The solution was prepared with distilled water and this composition was subsequently specified in Provisional British Standard 1391 : 1947.

Field tests : Outdoor exposure tests on specimens exposed at an angle of approximately 45°, facing approximately south, were commenced at Selly Oak, Birmingham, in July 1946, on protective schemes (*b*), (*c*), and (*d*), as above. These tests were made on specimens taken from all the nine sets, and three similar specimens were exposed throughout.

* The average thickness of the electrodeposit was within 20% of this figure for all the specimens.

* The error was found to be due to the use of a spring-loaded impact machine which had been calibrated to deliver a blow of 18 lb./in. Unfortunately, when the calibration was made the machine was not clamped to a bench, whereas this was the case when it was used for the present work. The effect of clamping down was to increase the energy of the blow actually absorbed by the specimen as indicated, probably because of the lightness of the machine itself, the whole instrument weighing only 13½ lb.

Table XIV

RESULTS OF SEA-WATER SPRAY TESTS ON SPECIMENS PRIMED WITHOUT PHOSPHATING (INDIVIDUAL LABORATORIES)

Specimens from Firm No.	Test Laboratory	Duration of Test to Failure, days, and Cause of Failure*						
		1	2	3	4	5	6	Average
1	*H*	1*g*	1*g*	3*gs*	1*g*	3*gs*	1*g*	1·7
2	*L*	13*g*	15*gs*	10*g*	8*g*	4*g*	6*gs*	9·3
3	*F*	5*gs*	5*g*	4*g*	3*g*	6*gs*	5*g*	4·7
4	*A*	3*g*	1*g*	2*g*	4*gs*	3*s*	2*g*	2·5
5	*G*	5*gs*	3*g*	3*s*	4*g*	4*g*	4*s*	3·8
6	*K*	2*g*	2*s*	2*s*	3*gs*	2*gs*	2*g*	2·2
7	*C*	1*g*	1*g*	1*g*	1*g*	1*g*	1*g*	1·0
8	*B*	3*g*	3*gs*	3*gs*	3*gs*	2*g*	3*gs*	2·8
9	*J*	1*g*	4*g*	2*g*	2*g*	3*s*	1*g*	2·2

* *g*—Failed through general rusting.
s—Failed at the scratches.

Control blanks: In all tests, bare-steel control blanks were exposed with the specimens as a check on the corrosiveness of the sea-water spray or of the atmosphere. These were taken from the same batch of materials as was used to prepare the coated specimens. The blanks were thoroughly degreased by swabbing with pure carbon tetrachloride, using three changes of swab and solvent. They were then degreased in carbon tetrachloride vapour for 5 min. or, alternatively, immersed for 5 min. in fresh pure carbon tetrachloride and allowed to drain vertically.

Thickness measurements: Direct determinations of coating thickness were made on representative specimens by means of the coating thickness tester developed by the Armament Research Department (*see* p. 487).*

In using this meter, which was primarily designed for the measurement of protective metallic coatings, for the present purpose, it was found necessary to insert a layer of tin foil of known thickness (about 0·2 mil) between the head of the magnet and the paint surface in order to prevent damage to the paint.

Methods of Assessing Failure—Observations on the behaviour of the specimens under test were made in each laboratory in a standard manner and recorded on standard forms. Criteria of failure were laid down similar to those described on p. 477, but it has been thought preferable to express the experimental results in terms of the following criteria of acceptability finally adopted for Provisional British Standard 1391 : 1947, which incorporate certain modifications made subsequently to the tests under discussion with the object of facilitating uniformity of interpretation between different laboratories:

(1) *On the front (protruding) surface of the impact dome:* Rust or rust-stain and any flaking, blistering, or other defect of the protective coating shall not extend beyond ¼ in. from the centre of the dome. In order to avoid any error due to drainage of rust-bearing solution downwards from the dome, the measurements shall be confined to the upper part of the dome.

(2) *On or at the scratches:* (*a*) There shall be no rust or rust-stain extending at any point beyond ⅛ in. from

* E. S. Spencer-Timms, *Journal of the Electrodepositors' Technical Society*, 1945, vol. 20, pp. 139–146.

Table XV

RESULTS OF SEA-WATER SPRAY TESTS ON SPECIMENS PRIMED AFTER PHOSPHATING (INDIVIDUAL LABORATORIES)

Specimens from Firm No.	Test Laboratory	Duration of Test to Failure, days, and Cause of Failure*						
		1	2	3	4	5	6	Average
1	*H*	> 9	> 9	> 9	> 9	> 9	> 9	> 9·0
2	*L*	15*g*	>17	>17	10*g*	>17	>17	>15·5
3	*F*	> 7	> 7	> 7	> 7	> 7	> 7	> 7·0
4	*A*	3*s*	4*s*	3*s*	> 8	5*s*	8*g*	> 5·2
5	*G*	7*g*	7*g*	> 7	7*g*	7*g*	7*g*	> 7·0
6	*K*	2*g*	2*g*	2*g*	2*g*	2*g*	2*g*	2·0
7	*C*	1*g*	1*g*	1*g*	1*g*	1*g*	1*g*	1·0
8	*B*	2*s*	4*s*	3*gs*	3*gs*	3*s*	3*s*	3·0
9	*J*	4*g*	8*s*	8*s*	> 8	> 8	> 8	> 7·3

* *g*—Failed through general rusting.
s—Failed at the scratches.

Table XVI

RESULTS OF SEA-WATER SPRAY TESTS IN LABORATORY D

Specimens from Firm No.	Duration of Test to Failure, days, and Cause of Failure*											
	Phosphated and Primed				Phosphated and Finished				Zinc-Coated, Phosphated, and Primed			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	13*g*	20*gs*	12*gs*	15	83*s*	47*s*	69*g*	66	9*gs*	10*g*	12*g*	10
2	8*s*	9*g*	14*g*	10	36*s*	50*s*	28*g*	38	14*gs*	10*g*	14*gs*	13
3	6*g*	5*s*	5*s*	5	23*s*	29*s*	6*s*	19	2*s*	3*gs*	3*g*	3
4	3*s*	2*s*	2*s*	2	9*s*	12*s*	9*s*	10	>29	>29	>29	>29
5	7*s*	22*gs*	17*gs*	15	34*s*	27*s*	22*s*	28	20*g*	20*g*	17*g*	19
6	5*g*	6*g*	7*g*	6	9*s*	9*s*	9*s*	9	>29	>29	>29	>29
7	3*g*	8*gs*	5*gs*	5	12*s*	7*s*	10*g*	10	22*g*	>29	22*g*	>24
8	6*g*	5*gs*	9*gs*	7	104*s*	104*s*	104*s*	27*g*	27*g*	27*g*	>29	>28
9	3*g*	6*gs*	2*s*	4	10*s*	10*s*	10*s*	10	7*s*	10*g*	12*gs*	10
Average	7·8				32·7				>18·3			

* *g*—Failed through general rusting.
s—Failed at the scratches.

the original boundaries of the scratches. (*b*) Except as in (*a*), there shall be no flaking, blistering, lifting, or other defect of the protective coating extending beyond $\frac{1}{32}$ in. from the original boundaries of the scratches. (*c*) In the case of prepared test-specimens the portions of the scratches lying within $\frac{3}{8}$ in. of the bottom edge shall be ignored.

(3) *General:* There shall be no flaking, blistering, or other defect of the protective coating and not more than 0·5% (by area) of rust and rust-staining on the upper half of the front or back surfaces of the specimen, *i.e.*, the part bounded by the top edge and a horizontal line parallel to this and 3 in. below it.

Experimental Results

Reproducibility of the Spray-Test Results—The results of the sea-water spray tests in the individual laboratories are recorded in Tables XIV and XV which refer, respectively, to specimens primed without phosphating and after phosphating. In view of the abnormal severity of the blow used to cause the impact dome (p. 482), breakdown at this point was disregarded. Otherwise, failure was assessed as stated above.

It will be seen from Tables XIV and XV that, with one or two exceptions, notably set No. 2 of the specimens primed without phosphating and set No. 4 of those primed after phosphating, the reproducibility of the individual results is reasonably good. This reproducibility is intimately connected with the question of sampling, which is discussed in greater detail in the last section.

Comparison of Tables XIV and XV will show that in six cases out of nine, the average duration of test to failure was significantly higher for phosphated and primed specimens than for the specimens primed without phosphating. The average life for all the

Table XVII

SEA-WATER SPRAY TESTS IN LABORATORY D. CONDITION OF THE ZINC-COATED, PHOSPHATED, AND PRIMED SPECIMENS AFTER 10 DAYS

(The figures are average values for the front and back or for both scratches)

Specimens from Firm No.	Undamaged Surface			Maximum Spread from Edges. 0·01 in.			Spread from Scratches. 0·01 in.					
							Maximum			Average		
	Rust, %	Blisters, %	Zinc Corrosion Products, %	Rust	Blisters	Zinc Corrosion Products	Rust	Blisters	Zinc Corrosion Products	Rust	Blisters	Zinc Corrosion Products
1	2	0·2	100	11	3	> 45	7	0	>13	3	0	>13
2	0·2	20	20	0	44	57	0	2	5	0	1	2
3	20	5	50	>100	>100	>100	>60	>60	>60	>7	>17	>17
4	(2 spots)	0·1	0	2	2	2	0	0	4	0	0	0
5	0	10	1	0	89	89	0	35	30	0	15	14
6	(1 spot)	0·2	*	2	7	*	0	3	*	0	1	*
7	0	2	10	6	18	59	0	10	9	0	4	4
8	0	5	80	0	3	>20	0	6	>20	0	4	11
9	0·2	10	5	27	34	34	17	40	40	6	14	14

* Indeterminate because of whiteness of paint.

phosphated and primed specimens exceeded 6·3 days as compared with 3·4 days for those that were not phosphated.

Results of the spray tests in the laboratory in which all nine sets were tested (laboratory *D*) are presented in Table XVI. With a few exceptions, the reproducibility of the results for individual specimens was again good.

In these tests the zinc-coated, phosphated, and primed specimens failed unexpectedly rapidly. On most of them considerable blistering and zinc-corrosion products had developed after the first few days. This is evident from the condition of these specimens after 10 days under test, which is summarized in Table XVII. The percentage blistering on the undamaged surface of the specimens after that period varied from 0·1 to 20%, so that if the criteria of acceptability were strictly applied all the specimens would have failed. If blistering is disregarded, however, the lives to failure of this type of protective scheme are as shown in Table XVI. It is doubtful whether this course is justifiable, and it is clear that further work is needed to elucidate the applicability of the sea-water spray test to painting schemes applied over zinc-coated steel.

The correlation between the results observed in the individual laboratories and those obtained in laboratory *D* is less satisfactory than could be desired. The average test durations to failure recorded in both cases for corresponding sets of specimens are compared in Table XVIII. Taking the figures as they stand, the correlation coefficient (Spearman's ranking coefficient) is 0·346; if the least concordant results, those for set No. 9, are disregarded, this value rises to 0·542. It is, however, fair to point out that the comparison involves ten different laboratories and that at the time these tests were made, Provisional British Standard 1391 : 1947 had not been issued. In the absence of standards, there must inevitably be some difference of individual opinion as to what constitutes, for example, 0·5% of surface rust, and it is reasonable to hope that, as a result of experience and the issue of standards, the reproducibility of the test as between different laboratories will prove much better than the figures appear to indicate.

Table XVIII

COMPARISON OF RESULTS OF SEA-WATER SPRAY TESTS IN LABORATORY D WITH THOSE OBTAINED IN INDIVIDUAL LABORATORIES

(Tests made on phosphated and primed specimens)

Specimens from Firm No.	Average Duration of Test to Failure, days		Test Laboratory
	Laboratory D	Individual Laboratory	
1	15·0	< 9·0	*H*
2	10·3	<15·5	*L*
3	5·3	< 7·0	*F*
4	2·3	< 5·2	*A*
5	15·3	< 7·0	*G*
6	6·0	2·0	*K*
7	5·3	1·0	*C*
8	6·7	3·0	*B*
9	3·7	< 7·3	*J*

Table XIX

LOSSES IN WEIGHT OF CONTROL BLANKS (6 IN. × 4 IN., 20 S.W.G.) IN THE SEA-WATER SPRAY TEST

Set No.		Loss in Weight, cg.		
		7-Day Test		28-Day Test
		Individual Laboratories	Laboratory D	Laboratory D
1	*H*	378	231	576
2	*L*	132	227	623
3	*F*	200	171*	600
4	*A*	143	192	713
5	*G*	159	180	506
6	*K*	205	132†	442†
7	*C*	258	209	635
8	*B*	257†	185	586
9	*J*	280	206	760
Average		224	193	605

* One specimen only; 345 cg. for another single specimen after 14 days.
† Single specimens.

Losses in Weight of Control Blanks—The losses in weight of the control blanks throughout this series of spray tests are summarized in Table XIX. With a few exceptions, the figures represent mean values for duplicate specimens exposed either for 7 or for 28 days. The reproducibility between duplicates of the same set was generally satisfactory.

It will be noted that variations occur from one laboratory to another or even within the same laboratory, *D*, where the tests on the different sets of specimens were not made concurrently. This variation may be due in part to the fact that the quantity of spray required to wet paint surfaces of different types varies. It is known, however, that the variation in the rate of breakdown of a protective scheme exposed to the sea-water spray is considerably less than that in the rate of corrosion of the control blanks, provided that a certain minimum figure is reached in the latter case. Consequently, it is considered sufficient to use the control blanks as a check that the conditions of spraying have been sufficiently severe to produce this desired minimum rate of attack. On the basis of the present and of other data, Provisional British Standard 1391 : 1947 stipulates that the loss in weight of the control blanks shall not be less than 1·4 g. per specimen over a 7-day period or 4·1 g. over a 28-day period. It will be seen that, with two exceptions, all the results shown in Table XIX conform to this.

Results of the Field Tests and Correlation with the Sea-Water Spray Test Results—The results to date of the outdoor exposure test at Birmingham are shown in Table XX. This test is still in progress as the majority of the specimens have not yet failed on their back sheltered surfaces and a number of the zinc-coated phosphated and primed specimens are in

good condition on the upper surface also. The average loss in weight of control blanks exposed over the first 77 days of the test was 5·68 g. This corresponds to an average corrosion rate of 4·0 mils per year, if the seasonal variation in the rate of corrosion is disregarded.

In view of the difficulty experienced in assessing failure of the zinc-coated specimens subjected to the sea-water spray test (p. 485), the following discussion will be limited to the phosphated steel specimens, whether primed only or primed and finished.* If the results of the outdoor exposure tests (Table XX) are compared with those of the spray tests conducted in laboratory *D* (Table XVI), it will be seen that the average life of the phosphated and primed sets of specimens was 77·8 days outdoors, as compared with 7·8 days in the sea-water spray test. This corresponds to an acceleration of ten times in the rate of breakdown. It would seem that the degree of acceleration achieved in the laboratory test decreases as the efficiency of the protective scheme increases, for, in the case of the phosphated, primed, and finished specimens, the average test duration to failure outdoors was $>$ 151·6 days as compared with 32·7 days in the laboratory test; the latter figures correspond to an acceleration of approximately five times.

It is satisfactory to record, as will be apparent from Fig. 13, that the correlation between results of the sea-water spray tests and those of the outdoor exposure tests is good. If statistical analysis is applied to the 18 sets of specimens as a whole, *i.e.*, without distinction as to whether the painting scheme consists solely of a priming coat or of both priming and finishing coats, the correlation coefficient (Spearman) between the two sets of results is found to be 0·813. It would be too much to expect that a laboratory test of this type would place 18 protective schemes in the exact order observed in an outdoor test, but the degree of correlation found encourages the belief that the sea-water spray test will provide a useful general indication of the probable behaviour of protective schemes embracing phosphating, followed by stoving paint, and it should certainly prove of assistance in discriminating good schemes of this type from bad ones.

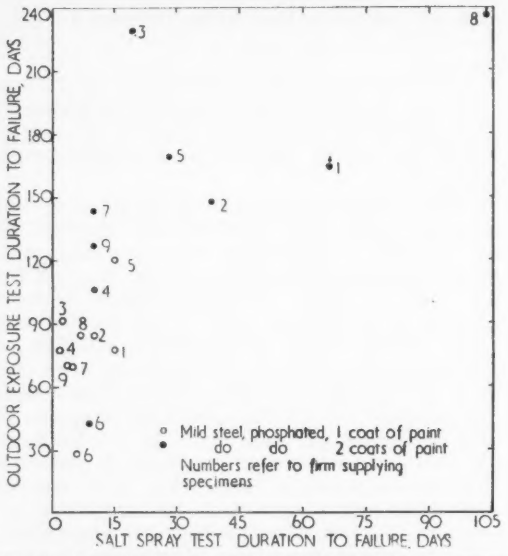


Fig. 13—Correlation of results of the A.R.D. sea-water spray test with those of outdoor exposure

* It is clear from a cursory comparison of Tables XVI and XX that there is no correlation between the results of the sea-water spray test and those of outdoor exposure, so far as the zinc-coated, phosphated, and primed specimens are concerned.

Table XX

INTERIM RESULTS OF OUTDOOR EXPOSURE TESTS AT BIRMINGHAM

(Duration of test to date: 363 days)

Set No.	Duration of Test to Failure, days, and Cause of Failure*											
	Phosphated and Primed				Phosphated and Finished				Zinc-coated, Phosphated, and Primed			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	77*g*	56*g*	98*gs*	77	77*g*	>271	144*s*	>164	271*g*	>363	271*gs*	>302
2	77*g*	77*g*	98*g*	84	98*s*	165*s*	182*s*	148	271*s*	271*g*	165*g*	236
3	98*g*	98*g*	77*g*	91	144*g*	271*gs*	271*gs*	229	271*g*	271*g*	271*gs*	271
4	77*g*	56*g*	98*gs*	77	98*s*	77*s*	144*s*	106	182*g*	>363	271*g*	>272
5	98*g*	119*g*	144*g*	120	182*s*	182*s*	144*s*	169	271*gs*	>363	325*g*	>320
6	35*s*	21*s*	28*s*	28	35*s*	56*s*	35*s*	42	325*g*	>363	325*g*	>338
7	28*g*	144*g*	35*gs*	69	144*s*	119*s*	165*gs*	143	>363	325*s*	>363	>350
8	77*s*	77*s*	98*s*	84	>271	165*s*	>271	>236	144*g*	144*gs*	98*g*	129
9	77*g*	77*g*	56*s*	70	119*g*	98*s*	165*s*	127	271*g*	>363	182*g*	>272
Average	77·8				>151·6				>276·7			

* *g*—Failed through general rusting.
s—Failed at the scratches.

Table XXI

DEPTHS OF IMPACT DOME PRODUCED BY BLOWS OF DIFFERENT ENERGIES IN THE C.R.L. INDENTATION MACHINE

(The blows were applied to 20-S.W.G. mild-steel sheet)

Energy of Blow, in./lb.	Depth of the Impact Dome,* mils		
	Minimum	Maximum	Average
10	61	85	78
18	100	115	108
26	113	141	127
34	133	151	142

* This includes the thickness of the sheet itself, 36 mils, *i.e.*, the measurement given is the distance between parallel planes embracing the lower face of the sheet and the apex of the dome, respectively.

Effect of Varying the Energy of the Blow Used to Produce the Impact Dome—In order to investigate the effects of the energy of the blow used for producing the impact dome on failure at this point in the corrosion test, four sets of specimens, each comprising 16 similar phosphated and primed specimens and 16 similar phosphated, primed, and finished specimens of the standard size, 6 in. × 4 in. × 20 S.W.G., were supplied through the courtesy of four of the firms collaborating in these researches. Four different impact domes were made on each specimen in one laboratory by means of the falling-weight impact-machine designed at the Chemical Research Laboratory for use with Provisional British Standard 1391 : 1947.* The energies used to produce the blows were 10, 18, 26, and 34 lb./in. respectively. The average depth of the dome was determined for 12 representative specimens with the results given in Table XXI.

Four specimens of each set of 16, *i.e.*, 32 specimens in all, were subjected to the sea-water spray test in each of three laboratories, whilst a fourth set was given an outdoor exposure test at Birmingham.

The results of these tests are adequately represented for the purpose in hand by the data given in Table XXII, which relate to the sum total of all the results obtained in all three laboratories for the phosphated and primed surfaces.† It will be seen that three criteria of failure have been assumed in evaluating the results. These correspond to a permissible spread of breakdown, *i.e.*, rust, rust-stain, blistering, or other defect of the coating, measured from the centre of the dome, of 0·15, 0·20, and 0·25 in., respectively,‡ after 5 days' spray test. For purposes of comparison a similar analysis of the condition, as at 274 days, of the specimens exposed to the outdoor exposure test has been included in Table XXII.

On the basis of the laboratory-test results it was decided that the most suitable value for the energy of the impact blow was 18 lb./in., as used in the previous test series, coupled with a permissible spread of breakdown not exceeding 0·25 in. after 5 days' spray test. In the case of the tests under discussion, this would have permitted rather more than two-thirds of the specimens to pass the test (p. 489).

Coating Thickness Measurements—Values of the thickness of the various protective schemes are tabulated in Table XXIII. The results of direct determinations made with the A.R.D. thickness meter (p. 483) are compared with calculated figures deduced from the increases in weight of the specimens on painting and the appropriate paint constants. These calculations were made as follows :

$$t = g(1/D - v/d)/A(1 - v)$$

where t is the thickness in centimetres of the paint on a specimen of area A in square centimetres, g is the weight of dry paint on the specimen in grammes, D is the specific gravity of the mixed paint, d is the specific gravity of the volatile thinners, and $100\ v$ is the percentage of volatile thinners in the mixed paint.

The phosphate coatings on these specimens were thin and no direct calculation was made of their thickness. This thickness was included with that of the paint film, the total thickness of the phosphate coating and of the paint being calculated from the increase in weight of the blank steel specimens after phosphating and painting, on the assumption that the whole protective film consisted of paint. Clearly, this introduces a slight error, inasmuch as there is generally some loss of steel in the phosphating process, and the specific gravity of the phosphate coating will differ slightly from that of the paint film. It is not thought, however, that any marked error is introduced thereby.

The thicknesses of the zinc coating were calculated from the weight W (grammes) of zinc on a panel of area A (square inches), using the formula $t = W/115A$.

Table XXII

EFFECT OF THE ENERGY OF THE INDENTING BLOW ON FAILURE AT THE IMPACT DOME (PHOSPHATED AND PRIMED SPECIMENS)

Permissible Spread of Breakdown, in.	Energy of the Indenting Blow, lb./in.	Specimens passing the Test, %	
		Sea-Water Spray Test, 5 days	Outdoor Exposure, 274 days
0·25	10	91	94
	18	78	81
	26	66	63
	34	34	50
0·20	10	72	94
	18	47	63
	26	19	44
	34	9	13
0·15	10	52	63
	18	29	25
	26	10	13
	34	13	0

* For a description of the machine, *see* the Standard in question.

† The reproducibility between different laboratories was good, and similar results were observed for the phosphated, primed, and finished specimens. The losses in weight of control-steel blanks after 5 days' test averaged 0·199, 0·207, and 0·260 g. in the respective laboratories and complied with the requirements of B.S. 1391 : 1947.

‡ In the case of one laboratory, results for a spread of 0·15 in. only are available.

Table XXIII

OBSERVED AND CALCULATED THICKNESSES OF PROTECTIVE SCHEMES COMPRISING PHOSPHATING AND/OR STOVING PAINTS

Set No.	Total Thickness of Protective Scheme, mils							
	Primed without Phosphating		Primed after Phosphating		Phosphated, Primed, and Finished		Zinc-Coated (0·39 mil), Phosphated, and Primed	
	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated
1	0·38	0·37	0·67	0·65	1·97	1·70	0·96	0·97
2	0·40	0·49	0·50	0·57	1·86	1·74	0·78	0·96
3	0·35	0·44	0·56	0·63	1·82	2·07	0·68	0·93
4	0·37	0·57	0·58	0·68	2·77	2·41	0·87	1·10
5	0·31	0·38	0·37	0·47	0·85	0·92	0·50	0·80
6*	1·06	1·17	1·15	1·27	1·39	1·49	1·40	1·59
7†	...	0·80	...	0·85	1·39	1·29	...	1·16
8	0·56	0·61	0·72	0·75	1·91	1·89	0·92	1·05
9	0·33	0·65	0·35	0·59	1·14	1·56	0·76	1·35
Average‡	0·47	0·59	0·61	0·70	1·71	1·72	0·86	1·10

* The thickness measurements on the specimens of this set were made without the interposition of tin foil between the magnet head and the paint film.

† In this case several layers of tin foil proved insufficient to prevent damage to the priming paint, so that thickness measurements were impracticable, except for the fully finished specimens.

‡ Omitting set No. 7.

It will be noted that the agreement between the observed and the calculated values is reasonably good, except in the case of set No. 9 and of the zinc-coated, primed, and phosphated specimens.* It may, therefore, be concluded that the use either of the A.R.D. thickness meter or of indirect calculations based on observations of the weight of paint applied, coupled with determinations of the paint constants, will afford a useful tool for controlling the thickness of protective schemes of the types in question applied to light-gauge steel sheets. This thickness is a matter of great practical importance.

* In the latter case the calculated values are in general significantly higher than the observed ones. This discrepancy may be due to loss of zinc in the phosphating bath.

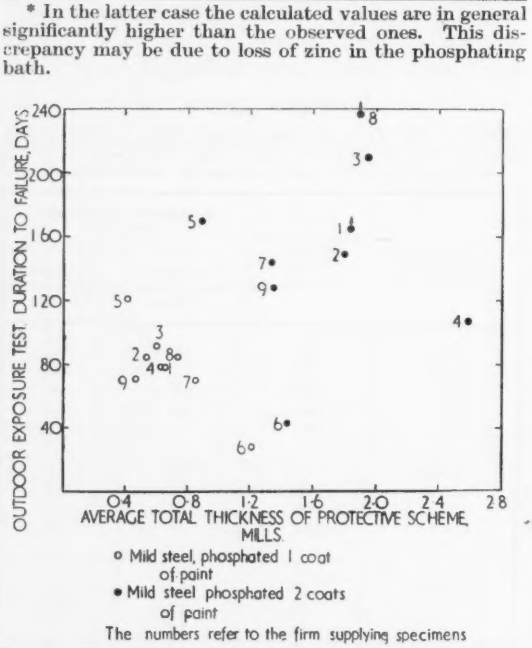


Fig. 14—Correlation of duration to failure in outdoor exposure test with thickness of protective scheme

It is of interest to carry the matter a stage further and to compare the observed lives of the protective schemes in the outdoor exposure test with the total film thickness. This is done in Fig. 15. There is a fair correlation between the two variables. The protective schemes of set No. 5 are well above the average whilst those of set No. 6 and the two-coat scheme of set No. 4 are abnormally poor. If these five protective schemes are omitted from the comparison, the correlation coefficient (Spearman) between the duration of exposure to failure and the total thickness of the protective scheme becomes 0·802.

It may be concluded, therefore, that in the case of light-gauge steel components, as in that of the protection of heavy structural steelwork, careful attention should be given to ensuring an adequate coating thickness of the protective scheme if good practical results are to be achieved.

Discussion of Results

Choice of the Criteria of Failure for the Sea-Water Spray Test—As already stated, through the progress of the Sub-Committee's investigations there have been changes and adjustments in the methods of assessing breakdown of the protective schemes ; this is evident from a comparison of the sections on Assessment of Breakdown (p. 477) and on Methods of Assessing Failure (p. 483). There would be no point in giving an historical account of these changes but, as they have been primarily made to increase the accuracy with which the point of failure of the protective schemes under test can be estimated, it is pertinent to refer to the most serious difficulties encountered in this connection. These are discussed briefly below.

(i) The visibility of the rust varied considerably with the colour of the paint ; for instance, on red or

brown surfaces it was easy for minute rust spots to escape unnoticed. The remedy adopted here was to allow a small but definite quantity of rust (0·5% of rust was ultimately adopted for a 5-day test) and to define this by means of a suitable photograph. This was better than stipulating that there should be no rusting, since a single microscopic rust spot could then be regarded as failure.

(ii) Different paints were found to require greatly differing quantities of spray to wet their surfaces to the same extent. This is due to the absorption of the spray by some porous paint surfaces and not by others. The wording of the provisional specification was altered so as to stipulate that the specimens should be covered with droplets after spraying instead of specifying the application of a fixed weight of spray as before. This had the effect of permitting some latitude in the weight of spray applied, to meet the variations in the quantity required to cover different types of paint films satisfactorily.

(iii) At the scratches an appreciable amount of under-rusting was observed to occur in some cases, even when the paint surface round the scratch remained free from rust or rust-staining. As a rule, this under-rusting was connected with the appearance of blisters on the paint at the scratches—the wording of the specification was revised in such a way as to reduce the possibility of ambiguity in the interpretation of failure at the scratches.

(iv) In the case of the zinc-coated, phosphated, and primed specimens, white corrosion products appeared. It was difficult to distinguish these in the early stages from the dry crystals of salt which were also present occasionally on the surface. When the specimens were wet with droplets, both salt and corrosion products disappeared, only to reappear later. The corrosion products, being white, were almost invisible on white- or cream-coloured paints. These white corrosion products also tended to mask the appearance of blisters and even to a less extent of rust and rust-staining.

In this case, unfortunately, no method has yet been found of overcoming the difficulty and it was considered advisable, therefore, to leave stoving paints applied over metallic coatings outside the scope of the specification for the time being.

(v) In the case of some of the protective schemes tested, a few specimens had been inadvertently fingered in the course of preparation. These finger prints rusted rapidly and led to an unnaturally short life. The obvious remedy is to use care in the handling of the specimens.

Choice of Reasonable Standards of Performance for Specification Purposes—If it be accepted that the primary object of specifications is to assist industry, then it is clear that there is no point in laying down a standard of performance which it would be unreasonably difficult to meet under industrial conditions. In the case under discussion, the specimens giving the results described in this section were prepared under industrial conditions in the works of eight different firms, each of which would be recognized as a firm of standing in the particular section of industry concerned. The results may therefore be accepted as a fair average sample of good current industrial British practice for the protection of light-gauge steel by phosphating and stove-painting.

In the light of these facts, the Sub-Committee felt that it would be reasonable when laying down standards of performance for protective schemes in the sea-water spray test, to choose the criteria of acceptability in such a way that two-thirds of the sets of samples tested would have complied with the specification. Further, although it is clearly difficult to assess correctly the relative importance of failure by general rusting and as a result of damage, it was felt that so far as practicable, the test stipulations should be so framed that failure was equally likely to be observed from both causes.

With these objects in view the extensive data obtained in the collaborative investigations described in this section were subjected to detailed analysis. It would be tedious to record the whole of this here and it will suffice, by way of example, to indicate the method by which the criterion of acceptability for rust and rust-staining on the general surfaces of the specimen was fixed.

The method of attacking the problem was as follows. The standard report forms for the individual specimens primed after phosphating* were studied, and records were made of the numbers that would have failed after certain periods of exposure, had certain criteria of acceptability for rust and rust-stain been adopted. These criteria were 4 rust spots, 6 rust spots, 0·2%, 0·5%, and 1% of rust, respectively. The results of such an analysis of the inspections after 4 days' test are shown in Fig. 15. A distinction is made between individual specimens and sets of specimens. In the latter case, all the three or six specimens in a given set have to pass the test if the set is to be accepted as satisfactory; this obviously leads to a higher standard than that deduced from consideration of the specimens as

* The provisional specification is solely concerned with phosphated and stove-painted specimens.

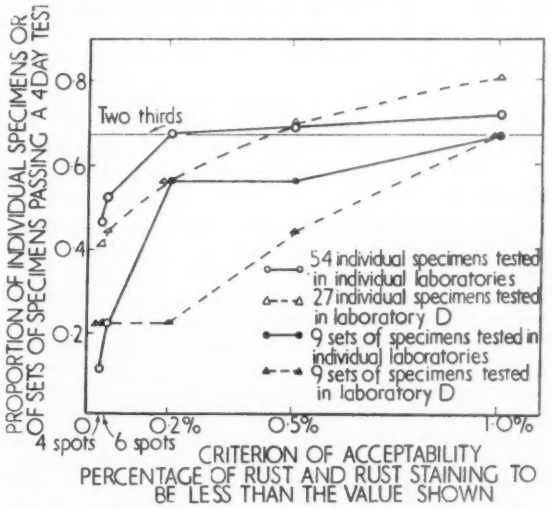

PROPORTION OF INDIVIDUAL SPECIMENS OR OF SETS OF SPECIMENS PASSING A 4DAY TEST
0·8
0·6
0·4
0·2
Two thirds
54 individual specimens tested in individual laboratories
27 individual specimens tested in laboratory D
9 sets of specimens tested in individual laboratories
9 sets of specimens tested in laboratory D
4 spots
6 spots
0·2%
0·5%
1·0%
CRITERION OF ACCEPTABILITY
PERCENTAGE OF RUST AND RUST STAINING TO BE LESS THAN THE VALUE SHOWN

Fig. 15—Proportion of samples satisfying various criteria of acceptability for rust and rust-staining after exposure to the sea-water spray test for 4 days

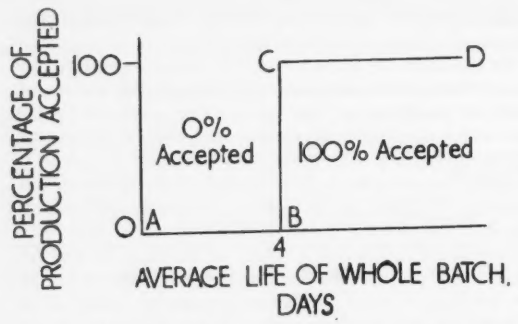


Fig. 16—Diagrammatic representation of an ideal sampling acceptance test

individual samples. It has also been thought advisable to keep the results of the tests made in individual laboratories separate from the results obtained in laboratory *D* where all nine sets of specimens were tested.

The general conclusion reached from Fig. 15 is that a stipulation that the amount of rust and rust-staining on the upper half of the front or back surfaces of the specimen shall not *exceed* 0·5% (by area) after a 5-day test is a reasonable one for this type of coating in the present stage of industrial development. The increase in the test duration from 4 to 5 days would render the test correspondingly more severe, but this is eased by the fact that 0·5% of rust and rust-stain is permitted, whereas the permissible amount deduced from Fig. 15 would be less than this. Moreover, the data shown in Fig. 15 include all nine sets of specimens, *i.e.*, sets Nos. 7, 8, and 9, in which the priming coat is intended as a surfacing coat only (p. 482). If these three sets of specimens were excluded the proportion of the remainder passing the test would be appreciably increased.

Similar methods of analyses were applied to the other criteria of failure, *i.e.*, the spread of failure from the edges, from the dome, and from the scratches, and the values so obtained have been incorporated in Provisional British Standard 1391 : 1947.

A STATISTICAL STUDY OF THE A.R.D. SEA-WATER SPRAY TEST AS AN ACCEPTANCE TEST AND AS A CONTROL METHOD FOR STABILITY OF PRODUCTION

Introduction

It is evident from the brief discussion on p. 488 that the application of the sea-water spray test as a performance specification to control industrial production of the protective schemes concerned is intimately associated with the sampling clauses laid down in the standard, *i.e.*, the number of the samples that shall be taken and the proportion of them that shall be required to pass the test. For the immediate purpose of Provisional British Standard 1391 : 1947, it was agreed that three samples should be taken and that all three of them should be required to pass the test, but it was realized that this was not the ideal arrangement and that other sampling procedures might be substituted for this with advantage when the Provisional Standard was revised.

The Ministry of Works kindly undertook to investigate this aspect of the matter and a statistical investigation of the data obtained for industrial protective schemes (*see* p. 481) was made by the Planning and Analysis Section of their C.S.A. Division, with the assistance of the Division's Materials Section and Mr. D. Newman of the Ministry of Supply.

As a result, a memorandum was prepared which forms the basis of this section of the report. In brief, the individual test results observed for each of a set of similar specimens (Table XVI, etc.) were used to gain an indication of the probable average standard deviation of a collection of supposedly similar specimens when subjected to the sea-water spray test. This figure was then adopted as a basis for the statistical analysis which is given below. It should be noted that the same methods of treatment will be applicable to any type of test, but that the numerical results given are peculiar to the test under discussion.

Application of Acceptance Tests to Industrial Use

In essentials the performance test specified in Provisional British Standard 1391 : 1947 requires that a number of individual specimens, coated with the protective scheme, shall be subjected to the sea-water spray test under certain defined conditions and shall be examined after a specific number of days. An individual specimen shall be considered to have passed the test if the protective scheme applied to it does not then show more than certain stipulated degrees of breakdown.

The specification of (i) the duration of the test, (ii) the number of individual specimens from each batch to be submitted for test, and (iii) the minimum number of these individual specimens to be required to pass the test, is essentially linked with the statistical aspects of the problem, and these are discussed in subsequent paragraphs.

The criteria of acceptability laid down in P.B.S. 1391 : 1947 imply that a batch is acceptable if the average "accelerated-test-life" of *all* its members exceeds 4 days. An "ideal" test would therefore be one whose use resulted in 100% acceptance of all batches with an average life over 4 days, and 100% rejection of all other batches. This characteristic of the ideal test is represented diagrammatically in Fig. 16. But to achieve this ideal would require testing the whole batch—a patently impracticable procedure. In practice a decision on the disposal of the whole batch has to be made, knowing only the quality of a few specimens selected from the batch. It is clear, therefore, that some falling short of the ideal is inevitable, and two types of shortcomings may be recognized : (i) The risk of accepting a batch which should be rejected (consumer's risk), and (ii) the risk of rejecting a batch which should be accepted (producer's risk).

By the suitable choice of the specification referred to above it will be the aim to minimize these two risks without requiring an excessively complex or expensive test.

It is evident that it will not be possible to keep the consumer's risk down to reasonable limits unless the few specimens selected are submitted to a more severe test than would be necessary were the whole

batch tested. Further, by an application of statistical theory,* it is possible to calculate the appropriate severity of test, irrespective of the number of items to be submitted for test, so that for this number the supplier's risk will also be minimized. This calculation leads to the conclusion that tests of duration 5 days, for the few specimens selected, are the optimum for acceptance testing to a standard for the whole batch of 4 days.

The numerical values of the consumer's and producer's risks are still not fixed, since the number of items to test, and the minimum number to be required to pass, have yet to be chosen. All that the decision already made—to test for 5 days—ensures is that, when these further numbers are settled, no superior or even equally good arrangement could be reached by selecting some other test duration.

The consumer's risk must be considered paramount or else the intention to set and maintain a standard is not in any sense fulfilled. A standard level of consumer's risk of 2½% was accordingly set† and for various chosen "Numbers of individual specimens to be tested" the "Minimum number of specimens required to pass" was calculated so as to achieve this level of risk. The results are given in Table XXIV.

It is desirable to stress that the series of acceptance schedules shown in Table XXIV ensures that: (i) In all cases the consumer's risk is 2·5%, and (ii) in each case, for the particular number of specimens tested, the producer's risk is a minimum.

Choice of the Most Economic Number of Test Items

As each of the sampling schemes detailed in Table XXIV meets the consumer's interests equally well, it will suffice to consider the producer's point of view in any further analysis. It is obvious that each producer would wish to select the sampling scheme that, in the long run, would prove most economic for him. The achievement of this end will now be considered.

* Applications of Quality Control—*V*: Quality Control by Limit Gauging. *Production and Engineering Bulletin*, October 1944: Ministry of Supply.

† This means that, in the long run, the consumer will accept 2½% of batches which, in fact, just fail to attain the standard. For inferior batches the risk rapidly becomes negligible as the quality deteriorates.

Table XXIV

SAMPLING SCHEMES (SCHEDULES OF ACCEPTANCE) FOR A 2·5% CONSUMER'S RISK IN THE A.R.D. SEA-WATER SPRAY TEST

(In all cases the specification referred to on p. 490 applies and the test duration is 5 days)

Sampling Scheme	Number of Specimens to be Tested	Minimum Number of Specimens Required to Pass the Test, in order that the Whole Batch be Accepted
I	3	3
II	5	4
III	12	7
IV	17	9
V	25	12
VI	30	14
VII	38	17
VIII	44	19
IX	50	21
X	58	24
XI	64	26
XII	76	30

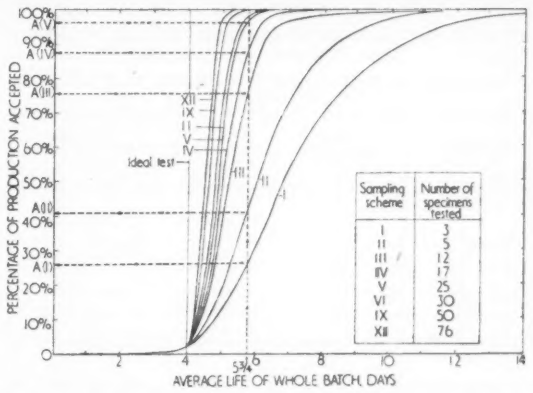


Fig. 17—Effect of various sampling schemes on the efficiency of the A.R.D. sea-water spray test

The efficiencies of the sea-water spray test for a representative selection of the sampling schemes detailed in Table XXIV are shown diagrammatically in Fig. 17. The method of presentation is similar to that adopted for the "ideal test" in Fig. 16. For each of the sampling schemes selected, the probability that the sample will pass the test (which is equivalent in the long run to the percentage of production accepted) is shown as a function of the true average life of the whole batch, could this be determined.

It is evident from a general inspection of Fig. 17 that the efficiencies of the tests involving the testing of the greater numbers of specimens approximate to that of the "ideal test," particularly in reproducing the sharp corners at *B* and *C* and the upright portion *BC* of Fig. 16, whereas the tests involving fewer individual specimens are notably less clear cut. The point may be illustrated quantitatively by considering the effect of different sampling schemes for a given producer, say, one who consistently produces batches with an average test-life of 5¾ days. Values for the efficiency and producer risk in this case have been read off from Fig. 17 and are given in Table XXV.

Consider the relative merits of sampling schemes I and II in Table XXV for this producer. Scheme II is clearly the better, for by increasing the number of specimens tested from 3 to 5, obviously with only a small increase in his expenses, he will save having 15% (74% minus 59%) of all his batches rejected. It is in fact clear that, for him, it would pay to increase the number of specimens tested to well over 5.

At the other end of the scale, consider the relative merits of sampling schemes IX and XII. Here scheme XII, involving the substantially greater cost of testing a further 26 specimens, results in the saving of only 0·0495% (0·05% minus 0·0005%) of all batches produced. In general, the increased costs of the former would be expected to outweigh the latter trivial saving, and this procedure would be uneconomic; in fact the optimum test for this producer might well be based on sampling scheme VI.

Table XXV

EFFECT OF SAMPLING SCHEME ON EFFICIENCY AND PRODUCER'S RISK

(It is assumed that the batch has an average life of 5¾ days in the A.R.D. sea-water spray test)

Sampling Scheme	Number of Specimens Tested	Efficiency, Batches Accepted, %	Producer's Risk Batches Rejected, %
I	3	26	74
II	5	41	59
III	12	76	24
VI	30	98	2
IX	50	99·95	0·05
XII	76	99·9995	0·0005

This particular solution, however, only holds for this producer. It will be seen from Fig. 17 that a second producer, whose batches have an average life of 12 days, would ensure that over 99½% were accepted by using sampling scheme II, which involves testing only five specimens.

In any event it is clear that in each case there will be an optimum sampling scheme and that this will depend on the quality of the product and on the internal economy of the producer. The method by which each producer may determine his optimum sampling scheme is described at the end of this section.

The subject may be considered in an alternative manner. It is obvious that for any given sampling scheme the percentage of rejections will diminish as the average life of the batch sampled increases. This is clearly brought out by Fig. 17, from which the typical numerical relationships between these two variables shown in Table XXVI have been compiled.

Suppose now that no choice of sampling scheme is given to the producer, but that a definite scheme is specified, say, scheme II. Then by reading across line reference II of Table XXVI, it will be seen that a producer making a product that would have an average life under test of 6·8 days, will have 30% of his output rejected; by raising this average life to 7·4 days he will cut down his rejection rate to 20% and so on until, when he has raised his standard to 10·6 days he will have succeeded in cutting down his rejection rate to 2%, with which he may be satisfied. Considered in this sense, the fact that sampling scheme II is specified may be regarded as an incentive to producers to raise the standard of their average production to at least 10·6 days.

Control Methods for Stability of Production

The object of acceptance testing is to determine, with reasonable accuracy, whether or not a batch is up to standard. The normal method of doing this is to stipulate the minimum number of passes required, out of a given number of specimens tested in a specified way, if the whole batch is to be accepted. Industrial quality control, however, has the object of detecting fluctuations in quality, both up and down, either as soon as they occur, or if they persist. In tests analogous to those already discussed, therefore, it is necessary to specify a maximum as well as a minimum permissible number of successes. It is usual to specify also the mean number of successes expected and to plot the results from successive batches on a "Quality Control Chart,"* but it is not appropriate to discuss this at length here.

Consider a producer whose batches have an average test-life of 7 days, and who takes three specimens from each batch (as for scheme I of the acceptance tests) and submits them to the acceptance test prescribed. Further, consider two alternative situations: (i) When he requires to know when the quality of a single batch has fluctuated, in which case his judgment must be based on the results of tests from only three specimens, and (ii) when he is content only to detect fluctuations which persist for 10 batches—when, by pooling all results, he will have results from 30 specimens.

The characteristics of procedure (i), involving tests on three specimens, are defined by the curves plotted in Fig. 18 (*a*). These show the maximum, mean, and minimum values of the number of successes to be expected, calculated on the basis of the observed distribution of the results of tests on industrial protective schemes (*see* p. 481 *et seq.*). It will be seen that a vertical line corresponding to an average life of 7 days for the whole batch (the quality of the producer concerned) cuts the "lower-limit" curve at 0·7, the mean curve at 2·5, and the upper-limit curve not at all. This procedure, therefore, can give the producer concerned no warning of a *rise* in his quality,

* Quality Control Charts. B.S. 600R : 1942. British Standards Institution.

Table XXVI

NECESSARY AVERAGE LIFE FOR THE WHOLE BATCH TO ENSURE A GIVEN PERCENTAGE OF ACCEPTANCE USING A GIVEN SAMPLING SCHEME

Sampling Scheme	Number of Specimens		Average Life for the Whole Batch, days					
	Tested	To pass	70% accepted	80% accepted	90% accepted	95% accepted	98% accepted	99% accepted
I	3	3	8·1	9·0	10·4	11·5	13·1	14·1
II	5	4	6·8	7·4	8·6	9·7	10·6	11·1
III	12	7	5·6	5·9	6·2	6·6	7·5	8·1
V	25	12	5·0	5·2	5·4	5·7	5·9	6·1
XII	76	30	4·6	4·7	4·8	4·9	5·0	5·1

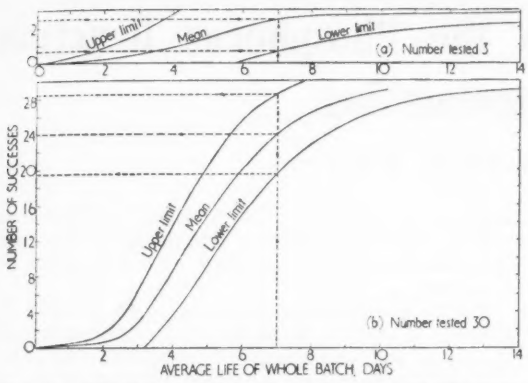


Fig. 18—Characteristics of the A.R.D. sea-water spray test as a control method for quality of production. (*a*) Tests on individual sets of 3 specimens each, and (*b*) tests on 30 specimens (10 individual sets of 3)

no matter by how much, since the maximum number of successes possible—3 out of 3—is to be expected frequently in any case. Admittedly, a warning of a fall in quality can be obtained if the number of successes falls short of the lower limit, 0·7, *i.e.*, by there being three failures, but this is not certain to happen unless the protective treatment is not applied at all, and no doubt simpler methods could be devised to guard against this. In this case, therefore, the acceptance test is almost valueless for use as a method of quality control.

The characteristics of procedure (ii)—with 30 individual test-results—are recorded in Fig. 18 (*b*). For this same producer—with batches having an average test-life of 7 days—the appropriate control chart values are seen to be upper and lower limits of $28\frac{1}{2}$ and $19\frac{1}{2}$, respectively, with a mean of 24. He will therefore get warning of a rise of quality by obtaining 29 or more successes and of a fall by obtaining 19 or less. But, also from Fig. 18 (*b*), these same values are seen to be the *lower* and *upper* limits respectively of produce of quality $13\frac{1}{2}$ and $4\frac{3}{4}$ days. Thus, even the adoption of this procedure, involving as it would waiting for the results of ten sets of test-results to accumulate, would only indicate with certainty to this producer that the quality of his product had fluctuated when the average life of the batch rose to $13\frac{1}{2}$ days or more or fell to $4\frac{3}{4}$ days or less—patently a weak indication, considering the trouble required. The fact is that special tests are required for quality control, and tests designed for another purpose cannot readily be adopted.

CONCLUSIONS

The main conclusions drawn from this analysis may be summarized thus :

The A.R.D. sea-water spray test may be regarded as suitable for acceptance purposes, although a final discussion on this point should be deferred until more data are available regarding the correlation between the behaviour under service and test conditions, respectively, of the protective schemes to which it is applicable.

All the sampling schemes (schedules of acceptance) listed in Table XXIV adequately safeguard the consumer's interests. A decision as to the actual scheme to be used in any particular case may be reached either by permitting the producer to select his own sampling scheme from the series according as to what is most economic for him or, alternatively, by choosing the scheme in such a way as to provide an incentive to the producer to raise the general quality of his output.

The sampling schemes (schedules of acceptance) prescribed in Table XXIV do not provide a suitable basis for production control, for which other types of test, specially designed for the purpose, are necessary. Apart from this limitation it is doubtful whether the A.R.D. sea-water spray test, which requires a minimum time of 5 or 6 days, would be sufficiently rapid for most industrial control purposes.

Practical Determination of the Most Economic Sampling Scheme

In order to ascertain the most economic sampling scheme for his purpose, the producer must first determine the average life in days of his produce in the A.R.D. sea-water spray test. Let us assume for purposes of illustration that this is $5\frac{3}{4}$ days.

Next, using Fig. 17, he erects a vertical line from the point appropriate to his average quality, and reads off from the various curves the percentages of his produce, A, that would be accepted under the different sampling schemes. Thus, in the specific case mentioned, the percentages are $A_1 = 26$, $A_2 = 41$, etc., where the suffixes 1, 2, etc., refer to sampling schemes I, II, etc.

Let D be the cost of producing a batch of produce, C_1 that of testing the three specimens of scheme I, C_2 that of testing the five specimens of scheme II, etc.

The producer then calculates the total cost of operating each sampling scheme, T. This consists of the cost of the test C and that of the fraction of the batches wasted, namely, $D(100 - A)/100$; hence :

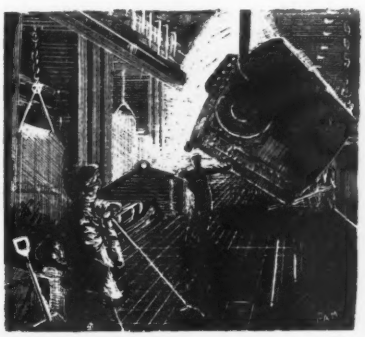
$$T_1 = C_1 + D(100 - A_1)/100 = C_1 + 0{\cdot}74D$$

in the case quoted, and :

$$T_2 = C_2 + D(100 - A_2)/100 = C_2 + 0{\cdot}59D$$

in the case quoted, and so on.

When these calculations are completed, it is a simple matter for the producer to select the sampling scheme yielding the lowest value of the total cost, T.



Note on Further Work on the Phosphorus Reaction in Basic Steelmaking

By P. Vajragupta, Ph.D., A.R.S.M.

In the preceding two papers[1, 2] concerning a laboratory investigation of the phosphorus reaction in the basic steelmaking process, it was shown that there existed an empirical relationship between the total lime content of the slag and the primary phosphorus equilibrium constant

$$\left[k = \frac{(P_2O_5)}{[P]^2\,(FeO)^5}\right]$$

and that, within the range of basic steelmaking temperatures, this relationship was defined by the general equation $\log k = n \log \Sigma CaO - c$, whose gradient n remained constant, whilst c varied with temperature. The slags employed were basic in character, covering a wide range of compositions typical of general basic steelmaking practice.

The range did not quite cover the more basic tapping slags normally practised in British industries, and in order to make this work complete and to test the validity of the relationship which has been put forward, further investigation has been carried out employing two types of slags of high lime/silica ratios, one containing low SiO_2 and high P_2O_5, and the other high SiO_2 and low P_2O_5. The experimental procedure was similar in all respects to that previously described. Some difficulties were experienced in controlling the bath temperature during the melt, as in each case the initial slag employed was rather viscous, and only by repeated opening of the furnace lid and adjustment of the electrodes was it possible to maintain a steady direct arc through the molten bath. The control of atmospheric oxidation by nitrogen streams was thereby rendered ineffective, with the result that most of the slags contained less lime than was originally intended.

Twelve melts were carried out, eight at 1585° C. and four at 1635° C. Table I contains the corresponding metal and slag analyses. In addition to phosphorus, the metal was analysed for manganese in order that the bath equilibrium conditions could also be assessed in the light of the manganese reaction. In Table I the values of $\log \Sigma CaO$, $\log k_1 + 5$, $\log k_2 + 5$, and K_{Mn} have been evaluated and inserted, where k_1 and k_2 represent the primary phosphorus equilibrium constants based on the analytically determined (FeO) and the total equivalent (FeO) contents of the slag, and $K_{Mn}[= (MnO)/(\Sigma FeO)[Mn]]$, the equilibrium constant of the reaction $Mn + FeO \rightleftharpoons MnO + Fe$ respectively. Examination of the slag compositions contained in Table I reveals that although most of the slags are somewhat high in iron on account of atmospheric oxidation mentioned above, they are, as far as the other constituents and the lime/silica ratio are concerned, comparable to industrial refining and tapping slags. In fact, slags *S*3 and *S*5 can be considered to be closely typical, whilst *S*8 contains a very low (FeO) content and during actual melting was found to be highly viscous.

On the basis of the analytically determined ferrous oxide content, the results are shown in Fig. 1, where $\log \Sigma CaO$ is plotted against $\log k_1 + 5$, with crosses representing the melts at 1585° C. and circles those at 1635° C., together with the three straight lines already established for the temperatures 1550°, 1585°, and 1635° C. With the exception of melt *S*8, which shows abnormal deviation, it will be seen that within experimental accuracy all the other results agree well with the previous findings. Melt *S*8, however, corresponds to a very high-lime slag of low iron oxide content, and it will be shown later, when the

Paper No. SM/A/31/47, submitted by the Steel Practice Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 29th January, 1948. The views expressed are the author's, and are not necessarily endorsed by the Committee as a body.

Dr. Vajragupta, at the University of Sheffield when the work reported was carried out, is now with the Government Mines Department, Bangkok, Siam.

Table I

METAL AND SLAG ANALYSES

Melt No.	Bath Temp., °C.	Time at Temp., min.	Metal Analysis, wt.-%		Slag Analysis, wt.-%									Log ΣCaO	Log $k_1 + 5$	Log $k_2 + 5$	K_{Mn}
			P	Mn	P_2O_5	CaO	SiO_2	ΣFeO	FeO	Fe_2O_3	Al_2O_3	MnO	MgO				
S1	1585	30	0·035	0·077	13·0	39·8	8·2	26·2	19·6	7·3	1·6	5·6	5·5	1·600	2·564	1·934	2·78
S2	1585	30	0·030	0·066	12·0	39·4	7·4	30·2	22·2	8·9	1·6	6·3	4·2	1·596	2·397	1·729	3·16
S3	1585	30	0·033	0·105	13·9	43·1	8·0	23·3	16·7	7·3	1·6	6·4	3·4	1·635	2·993	2·269	2·62
S4	1585	30	0·031	0·105	13·1	42·6	7·8	25·7	19·1	7·3	1·6	6·2	3·4	1·629	2·730	2·085	2·30
S5	1585	30	0·029	0·148	14·0	45·0	8·4	22·0	15·2	7·8	1·6	6·7	2·5	1·653	3·312	2·509	2·06
S6	1585	30	0·028	0·062	14·5	42·4	7·3	26·8	19·4	8·2	1·1	5·8	3·7	1·627	2·828	2·127	3·49
S7	1585	30	0·029	0·090	14·6	42·2	7·1	26·6	19·4	8·1	1·1	5·9	4·9	1·625	2·801	2·115	2·47
S8	1585	10	0·070	0·096	6·96	63·3	13·5	8·4	6·3	2·4	1·6	5·0	3·4	1·801	4·156	3·531	6·20
SX1	1635	30	0·026	0·103	5·54	41·5	9·2	32·6	24·8	8·6	0·9	5·3	6·2	1·618	1·941	1·348	1·58
SX2	1635	30	0·025	0·135	6·89	47·7	11·3	25·2	18·5	7·5	1·2	5·0	3·9	1·679	2·706	2·035	1·47
SX3	1635	30	0·024	0·103	6·61	44·8	10·8	28·0	20·6	8·2	0·9	5·0	6·1	1·651	2·490	1·824	1·73
SX4	1635	30	0·021	0·090	6·58	44·8	10·5	28·9	21·4	7·9	1·5	5·2	4·8	1·651	2·522	1·869	2·00

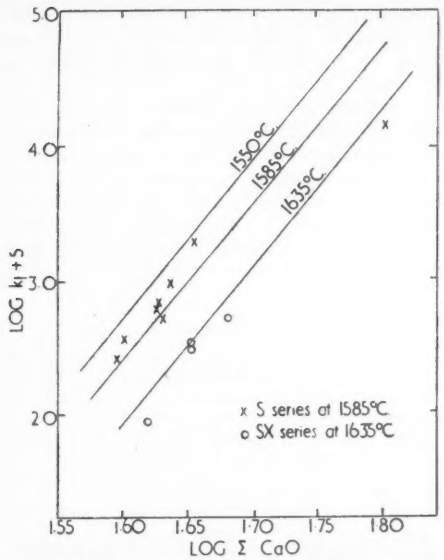


Fig. 1—Relation between log $k_1 + 5$ and log ΣCaO

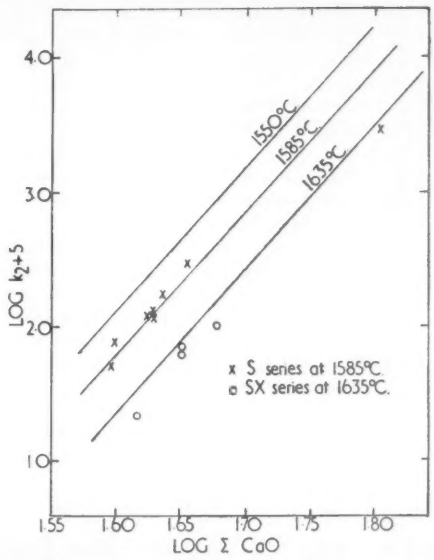


Fig. 2—Relation between log $k_2 + 5$ and log ΣCaO

manganese reaction is considered, that equilibrium conditions were most likely not attained in this case on account of the high viscosity of the slag.

In Fig. 2 the values of log $k_2 + 5$ for the twelve results are plotted against the corresponding log (ΣCaO), along with the three straight lines previously obtained for the temperatures 1550°, 1585°, and 1635° C.; similarly it will be observed that except in the case of melt *S*8 the agreement is satisfactory.

The manganese equilibrium constants for all the results shown in Table I, except melt *S*8, fall into two groups of approximately constant values of 2·61 and 1·70, corresponding to the two temperature ranges 1585° and 1635° C. These values compare well with those given in the literature on the manganese equilibrium in the basic process for the temperatures concerned. Melt *S*8, however, gave a value of 6·2 for the equilibrium constant at 1585° C., thus indicating the non-equilibrium conditions of the melt, most probably owing to the viscous nature of the slag. From the consideration of the phosphorus and manganese reactions, therefore, it can be concluded that the state of equilibrium was reached in all cases except melt *S*8, and as far as the former reaction is concerned, the present work seems to verify the empirical relationship formerly established.

Since the slags dealt with in this work were more basic than those previously studied, it was considered desirable to obtain some information concerning their constitution. For this purpose ten of the quenched slags have been examined by means of the X-ray powder method using cobalt radiation, and the results are reported in Table II, wherein will be found the details concerning the slags examined, the corresponding $(P_2O_5)/(P_2O_5 + SiO_2)$ molecular ratios, and the phases observed.

Examination of Table II reveals that, apart from the appearance of a free-lime phase in some of the slags, the results confirm the earlier X-ray and petrographic findings that quickly quenched basic slags consist essentially of a lime–silico–phosphate solid solution, dicalcium ferrite, and an oxide solid solution of FeO, MnO, and MgO. The occurrence of β-$2CaO.SiO_2$ solid solution in one slag and of α-hexagonal silicophosphate phase in the others calls for no comment since such constituents are to be expected according to the $(P_2O_5)/(P_2O_5 + SiO_2)$ ratios, as indicated in the preceding work.

Table II

RESULTS OF X-RAY EXAMINATION OF SLAGS

Slag No.	$\frac{P_2O_5}{P_2O_5 + SiO_2}$	CaO-Rich Phase	Silicophosphate Solid Solution	$2CaO.Fe_2O_3$	Oxide (Fe, Mn, Mg) O
S2	0·41	Not observed	α-Hexagonal solid solution	Present	Present
S3	0·42	,,	,,	,,	,,
S4	0·42	,,	,,	,,	,,
S5	0·41	,,	,,	,,	,,
S6	0·46	,,	,,	,,	,,
S8	0·18	Present	β-$2CaO.SiO_2$	Small	Small
SX1	0·20	,,	α-Hexagonal solid solution	Present	Present
SX2	0·21	,,	,,	,,	,,
SX3	0·20	,,	,,	,,	,,
SX4	0·21	,,	,,	,,	,,

The presence of free lime in some of the slags, however, deserved further attention, as it was found that the lines corresponding to the free lime in the X-ray patterns of these slags were shifted, indicating the effect of another constituent in solid solution. It is most probable, as Rait and Goldschmidt[3] have suggested, that MnO is capable of dissolving in lime in view of the common cubic structure and the close lattice parameters of the two oxides. In the P_2O_5-rich slags this lime phase was not observed. Possibly the lime which was in excess of the amount necessary to satisfy the SiO_2, P_2O_5, and Fe_2O_3 in these slags was not sufficient to form a separate phase, but remained dissolved in the (Fe, Mn, Mg) O solid solution, or if there was enough the amount thus formed was below the visibility limit of the X-ray method of detection.

As a result of the present investigation concerning slags of general industrial practice, it can be concluded that the empirical relationship between the total lime content of the slag and the primary phosphorus equilibrium constant which has been developed in the earlier work is capable of defining the phosphorus reaction in the basic steelmaking process and is independent of slag composition within the wide range of basic practice, provided that no fluorspar is used. Further, it becomes clear that in the control of dephosphorization in the refining process, low phosphorus in the metal can be attained by a judicious adjustment of the CaO, FeO, and P_2O_5 contents of the slag, according to the relationship established, without having to employ an unduly viscous slag of very high lime content.

References

1. Balajiva, Quarrell, and Vajragupta : *Journal of The Iron and Steel Institute*, 1946, No. I, p. 115P.
2. Balajiva and Vajragupta : *Journal of The Iron and Steel Institute*, 1947, vol. 155, Apr., p. 563.
3. Rait and Goldschmidt : *Journal of The Iron and Steel Institute*, 1945, No. I, p. 391P.

Note on a New Method for Checking the Profile of Wire-Drawing Dies

By J. G. Wistreich

The profile of the die is of prime importance in wire drawing. The usual practice is either to examine by optical projection the shape of a partly drawn wire, or to cast a soft alloy, *e.g.*, Wood's metal, into the die and to project the shadow of the plug thus obtained on to a screen. Neither method tells anything about re-entrant portions of the die-hole, yet, next to the angle of the reducing part of the die, the shape of the sizeing portion is a ruling factor in wire-drawing. It is possible, of course, to make two casts from both ends of the die and to match these, but this requires considerable skill and the greatest care.

There is clearly a need for a compound of rubber-like quality, so that the re-entrant cast can be withdrawn from the die. We have carried out tests with the dental compound Zelex (manufactured by the Amalgamated Dental Co., Ltd., London) and have found it eminently

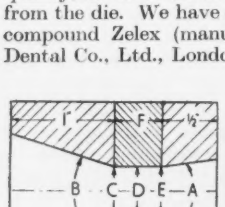


Fig. 1—Test-hole

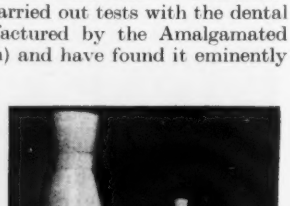


Fig. 2—Zelex replicas

suitable for checking die shapes to production standard, since it reproduces the shape reasonably accurately and the technique is extremely simple.

The compound, in powder form, is mixed in equal parts with warm water to a smooth paste, which sets in the die within 2–5 min. to the consistency of the white of a hard-boiled egg. The replica is withdrawn by gently levering the wide end and pushing the re-entrant end. The profile should be examined (by projection) immediately after withdrawal, as the compound hardens quickly and in half-an-hour shrinks about 0·002 in.

The accuracy of the Zelex replica was checked on a hole made to exact dimensions in a composite block, as shown in Fig. 1. It is seen from the following results that the replica of the composite hole underestimated the cone angles by not more than 5%, gave the throat diameter to within less than 1%, and the length of the throat to within 2% :

Dimension	Hole	Zelex	Wood's Metal
Test 1—Cones Cast Separately			
A	15° 14′	16° (+ 4%)	15° (− 2%)
B	30° 22′	31½° (+ 4%)	30¼° (− 1%)
Test 2—Cones Joined			
A	15° 14′	14½° (− 5%)	...
B	30° 22′	29¼° (− 3%)	...
Test 3—Cones with "36% Parallel"			
C	0·509 in.	0·509 in.	...
D		0·509 in.	...
E		0·508 in.	...
F	0·183 in.	0·186 in.	...
Test 4—Cones with "74% Parallel"			
C	0·509 in.	0·511 in.	...
D		0·508 in.	...
E		0·505 in.	...
F	0·370 in.	0·370 in.	...

Obviously the error depends on the bulk of the material that has to be forced through the throat, and the test hole exaggerated the re-entrant portion of wire-drawing dies ; in any case, with the rounded profile of the latter, the error in locating the ruling dimensions is of the same order.

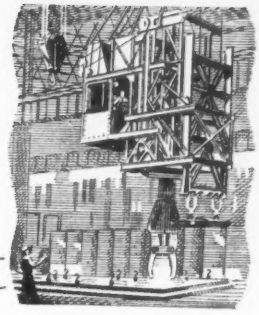
Figure 2 shows a replica of the test-hole and of two dies, 0·187 in. and 0·076 in. in dia.

Manuscript received 26th February, 1948.

Mr. Wistreich is in charge of the Drawing Section at the British Iron and Steel Research Association's Metal Flow Research Laboratory, 41, Doncaster Street, Sheffield.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



Electronic and Servo Electronic Controls and their Application to the Iron and Steel Industry

By W. G. Thompson, Ph.D., B.Sc.(Hons.), M.I.E.E.

INTRODUCTION

THE reasons for the general introduction of new methods of control in a manufacturing process are to be found in increased production, greater economy, improvement in the product, or a reduction in the effort demanded from the operators. There are three ways in which production can be increased: first, by speeding the working of the material; secondly, by reducing the time interval between operations; and thirdly, by reducing the proportion of material produced outside the permitted tolerances. These may be interpreted as faster accelerations, higher speeds or temperatures, quicker retardations or cooling, improved precision in transporting, handling and setting up material, better selection of material, more careful processing, and operation of the plant in the manner best calculated to minimize any inherent defects in the system. The object of this paper is to outline the principles of electronic measurement and control, and to indicate their contribution, both actual and possible, to the achievement of increased production. The other attainments of greater economy, improvement in the product, and reduced manual effort, will also be evident in many examples of electronic control.

The prevalent idea that the introduction of the light current technique to industry[1] should produce most useful results arises from its many successful war-time applications. In the transfer of these ideas to industry, especially to the iron and steel industry, where on one hand the massive size of the plant already in existence and established methods must be considered, and on the other where so much depends upon the skill and experience of the operators, it would appear that electronics should be directed to the improvement of control through refinements in existing methods. The installation of new plant may, of course, present wider and more novel opportunities for the application of the electronic technique.

Skill in the manipulation of large industrial plant is achieved through the integrated efforts of experienced workers exercising a selective judgment from observation by their senses, *i.e.*, sight, hearing, touch, etc. Whilst man has the ability to differentiate physical phenomena from their background he is mainly qualitative in his observation, and it is in this direction that electronics can assist in quantifying the data relevant to a manufacturing process and in presenting it in a form which will enable better use to be made of the equipment than that attainable by unaided human control. The initial step in applying electronic control is to obtain a selective measurement from the appropriate part of the process and then to translate that measurement into a form acceptable to electronic devices.

ELECTRONIC DEVICES AND THEIR SCOPE[2]

Electronic devices are characterized by the fact that the conduction of electricity through them takes the form of the discharge of free electricity, that is to say, electrons in a vacuum or electrons and positively ionized atoms in low-pressure gas or vapour. This difference enables electronic devices to be classified into two main groups as listed in Table I, with sub-groups according to whether they are valve devices, target devices, or discharge gaps. The essential construction of all these devices is a vacuated vessel, ranging in size from a small glass envelope to a large-diameter steel tank, exhausted to a very high degree of vacuum and containing an electron-emitting surface known as the cathode. This electrode may be a heated filament, often suitably coated to facilitate emission, or alternatively, a mercury pool to which an arc is maintained. A second electrode, called the anode, is arranged in the form of a metal cylinder, plate or gauze, or a block of graphite, according to the type of device, and serves as an electron-collecting surface.

Manuscript received 20th February, 1948.

Dr. Thompson is with the General Electric Company, Ltd., Witton, Birmingham.

Table I

SUMMARY OF ELECTRONIC DEVICES USED IN INDUSTRIAL CONTROL

Vacuum Group	Vapour Group	Remarks
Valve Devices		
1. Diode		Conduction by electrons from heated cathode. Used as rectifier for small currents, *i.e.*, milliampères
2. Triode		As above, but current continuously controllable by grids. Used as amplifier or oscillator
3. Tetrode		
4. Pentode		
	5. Diode	Electrons emitted from heated cathode ionize gas atoms; conduction by negative electrons and positive ions. Rectification up to few ampères
	6. Triode	As in 5, but current " triggered " by grid. Mercury vapour types up to 10 amp. and 1000 V. peak reverse. Grid-control current, milliampères
	7. Mercury arc rectifier (grid-controlled), multi-anode	(*a*) Glass bulb type: 10 to 400 amp. per bulb and all industrial voltages. (*b*) Steel tank, pumpless type: 100 to over 1000 amp./cylinder. All voltages (*a*) and (*b*). Electrons emitted from arc at mercury surface, arc conduction by ions and electrons, current released by grids. Grid current less than $\frac{1}{2}$ amp. Ignition device for starting, fan cooled
	8. Ignitron, single anode	As 7, but single anode and cathode in each air- or water-cooled vessel. Few ampères up to 800 amp./cylinder. Grid control effect provided by igniter taking up to 30 amp. peak, control grid sometimes added.
Target Devices		
9. Photo-electric cell	10. Gas-filled photocell	Electrons emitted from cathode when exposed to light or heat rays. Current, micro-amperes
10. Cathode-ray oscillograph		Electrostatic or magnetic deflection of electron beam focused on fluorescent screen or photographic plate. Used for high-speed recording and timing
11. X-ray tube		High-velocity electrons focused on to target anode produces intense electromagnetic radiation. Used for metallurgical examination
	12. Neon lamp	Conducts above designed voltage by gas ionized with electrons from cold cathode. Burns with constant voltage drop and provides voltage limiter or reference

Between these two electrodes, exercising control over the transit of electricity, is a third electrode known as the grid, which is usually in the form of a wire mesh, metal baffle, or a perforated graphite disc.

In vacuum valves conduction is solely by electrons, and the grid, when suitably electrically biased, has the ability to modulate the flow of electricity after the manner of a variable high resistance in the circuit. In the vapour devices the grid can only release the discharge consisting, in this case, of negative electrons travelling in one direction and positive ions going in the other. Once released the current is only limited by the external circuit of the anode and the grid cannot regain control until the current is interrupted externally. Characteristic curves are used to interpret the operation of the high-vacuum low-current valves, particularly the grid-voltage/anode-current characteristic of the vacuum triode. As will be seen from Fig. 1, the pattern of events impressed upon the grid is reproduced in amplified form in the anode circuit. Where greater amplification is required a double grid valve, the tetrode, may be used. This valve may have a " kink " in its voltage characteristic which can be overcome by a third grid as exemplified in the pentode or by a special construction of the tetrode.

No similar characteristics exist for the vapour or gas-filled valve, once the grid is released they are " full on." For this reason they are generally used with an alternating current supply, the flow of power being regulated by adjusting the phase of the positive impulses applied to the grid with respect to that of the anode voltage. The greater the delay angle the less the proportion of the voltage wave used and the less the amount of power transmitted. If the valve is arranged as a rectifying device giving an uncontrolled output E_o the controlled value is given as $E_c = E_o \cos \alpha$, where α is the angle of retardation of the grid impulses. This retardation can be attained mechanically by means of a phase-shifting transformer of the induction regulator type, as shown in Fig. 2 (*a*), in which the delay is related to the mechanical movement by the formula $\alpha = \theta \, . \, p$, where θ is the mechanical movement and p is the number of pairs of poles in the phase shifter. In electronic control it is usual to carry out the same process electrically, making use of a phase-shifting network consisting of a variable inductance L and a fixed resistance R, as shown in Fig. 2 (*b*), the variation in the inductance being obtained by saturating the iron core of the inductance with a superimposed D.C. winding. In this case the relation between the phase shift and the saturating D.C. control I_c is somewhat involved; firstly, $\cos \alpha = \dfrac{(\omega L)^2 - R^2}{(\omega L)^2 + R^2}$ and secondly, L varies according to the control current in a manner dependent upon the magnetization curve and design of the choke. In practical cases α and I_c can generally be made roughly proportional to one another; $\omega = 2\pi$ (frequency).

Thus in the progression from a low-power signal to a high-power control the light-current vacuum valves can be arranged to actuate a phase-shifting circuit which controls in turn the output of the heavy-

current vapour device in the desired manner. Strictly speaking, the term electronic control should be restricted to those operations in which high-vacuum valves provide the initial stage in the control sequence. There are alternative examples in which the control is applied direct to the vapour devices, and others in which the valves control machines without the intermediate vapour device stage, some of these will be included in the paper to give a better general picture.

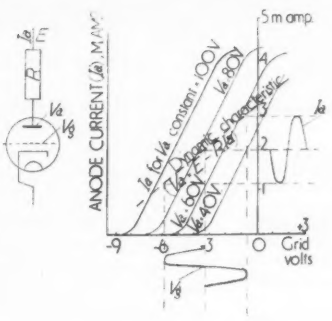


Fig. 1

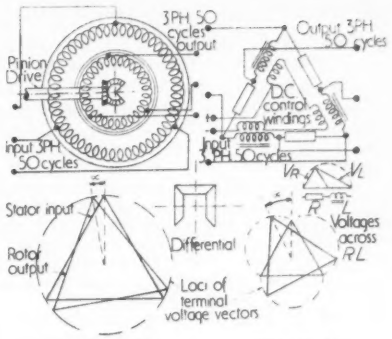


Fig. 2 (*a*) Fig. 2 (*b*)

Fig. 1—Dynamic and static characteristics of vacuum triode

Fig. 2—Mechanical and static methods of phase shifting. (*a*) Induction-type phase shifter (electrical differential): (*b*) Phase-shifting network

It is convenient at this stage to record that both types of valve contain no internal source of energy though there is, of course, a dissipation of heat due to their losses, and they require suitable ventilation or cooling. The complexity of the electronic circuits arises because the valves require a source of power for their operation, a low-voltage auxiliary power for maintaining the filament or cathode emission, and a source of signal voltage for the control grids. In addition to the valves there are numerous non-vacuum elements in the circuit, such as transformers, inductances, resistances, condensers, metal-oxide rectifiers, relays, fuses, etc., for imparting the correct circuit conditions and for processing the signal. Table I also shows the wide range of apparatus of the evacuated type appropriate to the iron and steel industry and their applications. The Table includes a number of devices of the " target " type, including the cathode-ray oscillograph, which is used for the high-speed recording of transient phenomena and the measurement of small time intervals ; the photo-electric cell, which releases electrons when exposed to light or heat waves, has been widely applied in iron and steel works for control purposes ; the reverse phenomenon is produced by the X-ray tube, whose industrial applications are well known, and which is beginning to be used as a continuous process control ; the betatron is now also being used for high-penetration X-ray work in industry ;[3] and the electron microscope, which demonstrates the way in which electronics can extend the optical faculties to the examination of most minute metallurgical forms. The list also includes neon lamps operating as voltage limiters or, alternatively, providing constant reference voltages.

ELECTRICAL INTERPRETATION OF MEASUREMENT AND CONTROL

The field of measurement essential to industrial control includes mechanics, light, heat, sound, electricity, chemistry, etc. Although electronic measurement *per se* lies somewhat outside the scope of this paper it is true to say that the measurements of one decade become the automatic controls of the next, and in this connection a recent paper by Polgreen[4] dealing with crack detectors, magnetic sorting bridges, sheet-thickness indicators, and vibration analysis, is of special interest. Table II is a survey of typical measurements of the kinds encountered in heavy industry and indicates the modes of converting these measurements into voltage signals necessary for the actuation of electronic circuits. The next stage is to convert a given signal into a control operation either to assist the human operator, who may control the machine directly or indirectly through auxiliary apparatus or, alternatively, the whole operation may be made automatic by electronically processing the signal up to the power level and in the form required for the correct functioning of the machine. The signal, whether applied direct or in processed form, can be used in various ways, as for example, comparison with a standard, the difference being used as an " error function " with the control designed to reduce the error to zero. Alternatively, the signal can be introduced into the operation of the machine in the form of a " compounding " effect. Examples of each of these methods are speed setting, and compensation for internal voltage drop, respectively. In some instances the continuous control or " steering " is preferred, in others an intermittent control is used giving the " on–off " effect as met with in certain types of voltage regulators or " hit and miss " governors.

Whether predetermined, or arising from the exigencies of the operation, control requirements can be visualized as being a function plotted on a time base, whilst the duty of the control mechanism is that of producing a second curve drawn to coincide as nearly as possible with the first. For a condition of uniformity such as constant speed the graph merely becomes a straight line parallel to the time axis ; where a variation is required the graph may be an inclined line corresponding to uniform acceleration ; or a series of steps may represent the operation or a complicated progressive curve. Deviations of the second curve from the first will be the result of over-shooting, or lack of response, or " hunting," in the control equipment, and it can be demonstrated that the underlying principles are the same whether the control is applied to a rolling mill, a furnace, an electric generator, or a chemical process. If, in addition, the quantities involved in the control stages can be conveniently expressed in mathematical form,

Table II

CONVERSION OF TYPICAL INDUSTRIAL MEASUREMENTS TO VOLTAGE SIGNALS

Measurement	Apparatus
Position of strip or ingot	Potentiometer slider, photocell or magnetic bridge
Speed of mill or strip	Tachometer-generator or time interval between operation of photocells or inductors set at fixed distance apart
Acceleration of mill or strip	Differential of tachometer-generator, change in time interval between impulses from photocells or inductors, accelerometer
Tension in strip or wire	Sag indicator converting to position measurement
Thickness of strip	Magnetic bridge
Change in thickness	Measure as change of length using phase shift of signals from two inductors, one on each side of rolls
Torque	Product of armature current and field strength in electric motor, torsionmeter
Power	Wattmeter methods or product torque and speed
Temperature of strip or ingot or melt	Resistance thermometer, thermocouple, thermopile, photocells
Flame temperature	Colorimetry by photocell
Pressure	Piezo crystal, resistance, inductance or condenser microphone
Fluid flow	Orifice plate and differential electrical manometer, bellows-actuated electrical relay

the recognition of well-known types of equations will indicate whether the control is likely to be unstable or impractical. As will be seen later, the intensive development which this technique has undergone in the last decade has raised control possibilities to new high levels, has made possible the rigorous treatment of electronic circuits with many variables, and has gone a long way to the elimination of unsuitable applications leading to costly empirical correction.

The value of this approach can be seen at once from a consideration of the speed/time curve of a rolling operation, where the result is the apparently innocuous requirement of uniform acceleration from rest followed by constant speed and uniform retardation. This process, regarded as a trapezoidal wave, can be proved to contain the following ascending order of odd harmonics:

$$y=\frac{4n}{\pi a}\left[\sin a\sin\theta+\frac{\sin 3a\sin 3\theta}{3^2}+\frac{\sin 5a\sin 5\theta}{5^2}+\ldots\right]\ldots(1)$$

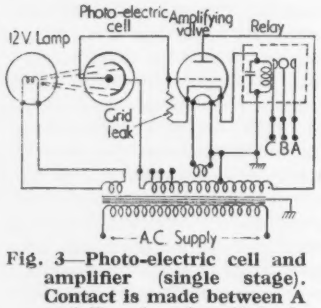


Fig. 3—Photo-electric cell and amplifier (single stage). Contact is made between A and B only when light is interrupted, and between B and C only with light shining into photocell

where n is the maximum speed and a is the acceleration time expressed as $a=\frac{t}{T}\pi$, t being the acceleration time in seconds and T the total time from start to finish. The means of control have, therefore, to be responsive to high frequencies if accurate following is to be attained. It is evident that to design for a sinusoidal acceleration and retardation will not alone suffice, as there is always the possibility of accidental sudden change of load or sudden internal disturbance in the system. The approach to problems of this kind has been considerably simplified by the concept of " transient response "[5] which can be examined theoretically and experimentally for a control scheme by various methods such as the response of the control to a rectangular wave which is of the form :

$$y=\frac{4n}{\pi}\left(\sin\theta+\frac{1}{3}\sin 3\theta+\frac{1}{5}\sin 5\theta+\ldots\right)\ldots\ldots(2)$$

and more conveniently identified with Heavyside's " unit function " **1**.

To anticipate the result of a later section of this paper, an ideal control system consistent in response to a rectangular wave should be capable of following any change in reference voltage whether produced by mechanical or electrical means. This should be understood to include the case of a machine following the movements of a manually operated controller. In the latter connection the indifferent performance of the human control has been investigated by Tustin[6] who describes the response as " not constant or consistent and it is non-linear, being essentially of a jerky nature." The author suggests that the introduction of continuously recording oscillographs with monitoring traces would materially raise the standard of manual control and would be a useful feature of many industrial control processes, particularly where measurement of material in motion is concerned, such as the application to " flying micrometers."

ELECTRONIC AMPLIFIERS AND SERVO SYSTEMS

The requirements of electronic amplifiers for industrial purposes are reliability and stability. The former calls for careful selection and arrangement of components in a well-protected and properly ventilated housing ; the second, for good circuit technique. There are various types in use ranging from the simple form, shown in Fig. 3, suitable for amplifying the signals from a photocell to operate an electromagnetic relay, to the multi-stage units for continuous

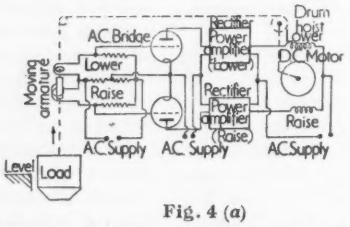


Fig. 4 (*a*)

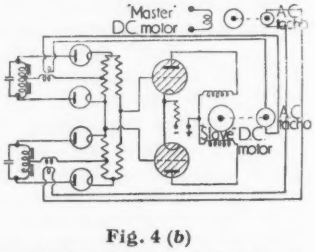


Fig. 4 (*b*)

Fig. 4—(*a*) " Phase-conscious " amplifier principle applied to load levelling. (*b*) " Frequency conscious " amplifier applied to synchronizing of D.C. drives

control incorporating special requirements such as overload protection, as shown in Fig. 4. Other variants are the phase-discriminating types,[7] illustrated in Fig. 5, used in synchronous drives or potential control. Industrial amplifiers, unlike the radio type, are usually D.C. amplifiers in which the output from one valve is directly coupled to the grid of the following valve through resistance circuits. This means that the output from the second stage is the reversed image of the input signal, and that opportunities for introducing overriding correcting signals may be limited due to the electrical continuity of the circuit.

For large powers associated with motor armature control it becomes necessary to add a power amplifier stage. The power amplifier may be of the dynamo-electric, electromagnetic, or electronic types, methods of applying electronic control to these different types have been used, but for the purposes of this paper it is proposed to direct attention to the last mentioned. Valves of the thyratron type or mercury arc rectifiers are required for the output stage, and the system adopted in Fig. 2 (*b*) may be used which includes the phase-shifting network mentioned on pages 497–499 of the paper. Apart from the amount of grid power required the process is identical for small valves or large rectifiers. The systems so far described are mainly of the " open loop " type, and provided that the amplification ratios of the different stages are kept within reasonable limits oscillations are unlikely to develop, although the accuracy of following may not be of the highest order. An improvement can be effected by feeding back an appropriate signal from the output to correct deviations from the ideal performance, the amplifier then becomes a servo mechanism and its design has to be treated accordingly.

Servo mechanisms have been studied with progressive thoroughness over the last twenty-five years, particularly during the recent war. The fundamental principles have been well set out by Brown and Hall[8] in America, and Whiteley[9] and others in this country. Because of the vital importance of this subject to the understanding of existing and possible future applications of electronic control, and because of the many new terms it has introduced, a brief account of the theory will be included here.

The general treatment is to split up the equipment into three units connected as shown in Fig. 6. The terms used to identify these units vary with different industries and applications, but for the purposes of the present paper it is sufficient to refer to them as the monitor, the controller, and the machine. In the diagram the machine feeds the output signal θ_o, regarded as a time function in the sense of the interpretation on pages 497–499, back to the monitor, which measures θ_o against the input signal θ_i. The difference or " error " θ is thus :

$$\theta = \theta_i - \theta_o. \quad \ldots\ldots(3)$$

The controller, which incorporates the amplifier, processes the error signal θ in a manner which will be represented by the mathematical operator A. This operator, though treated as a single entity, may in practice be the product of a number of operators each corresponding to a different stage in the controller. The output T_c from the controller may be written as a time function :

$$T_c = A\theta. \quad \ldots\ldots(4)$$

This control signal is fed to the machine whose response will also depend upon properties inherent in the machine itself, such as inertia, friction, etc., and will be defined by a second operator B. To complete the chain of events it is usual to postulate a disturbance arising from the reaction of the load; the difference $T_c - T_o$ processed by B, produces the output response :

$$\theta_o = B(T_c - T_o). \quad \ldots\ldots(5)$$

and thus completes the loop.

Equations (3, 4, and 5) can be combined by simple algebra to give the characteristic error equation of a servo system :

$$\theta = \frac{1}{1 + AB}(\theta_i - BT_o), \quad \ldots\ldots(6)$$

A being determined by the design of the controller, and B by the machine design. The next step is to write down the equation of motion of the machine according to its function, and the basic similarity of three different examples can be seen from Table III.

Linear differential equations such as these may be expressed in the notation of the operational calculus, as for example :

$$(p^2I + pF)\theta_o = T_c - T_o; \quad \ldots\ldots(7)$$

whence :

$$\theta_o = \frac{T_c - T_o}{p^2I + pF}. \quad \ldots\ldots(8)$$

Thus $\frac{1}{p^2I + pF}$ may be identified with B and θ expressed as :

$$\theta = \frac{\theta_i(p^2I + pF) + T_o}{p^2I + pF + A}. \quad \ldots\ldots(9)$$

It will be seen that the denominator combines the properties of the machine and the controller, and the transient stability can be examined by assuming all other effects suddenly removed, so that the product $\theta\,(p^2I + pF + A)$, and hence the denominator, is equated to zero, and for the system to be stable the roots of the equation must be negative and real. The example has a differential equation of the second order in the numerator and is described as a simple " zero velocity error " servo and may be considered as one of a group the first member of which would be a " position error " servo having a differential equation of the first order. In progressing through the group to " zero acceleration error " servos and

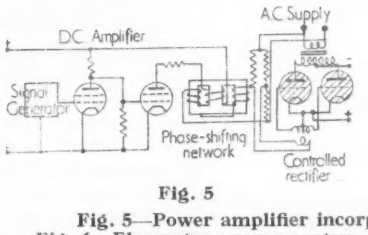


Fig. 5

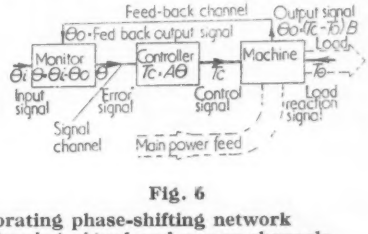


Fig. 6

Fig. 5—Power amplifier incorporating phase-shifting network
Fig. 6—Elementary servo system showing signal and power channels

Table III

SIMILARITY IN FORM OF TIME FUNCTIONS FOR DIFFERENT CONTROL PROCESSES

Type	Physical Phenomena	Equation
Machine	Inertia, friction	$I\frac{d^2\theta_o}{dt^2} + F\frac{d\theta_o}{dt} = T_c - T_o$
Furnace charge	Thermal capacity, conductance	$(M.S)\frac{d^2\tau}{t^2} + \frac{1}{c}\frac{d\tau}{dt} = T_c - T_o$
Electric circuit	Inductance, resistance	$L\frac{d^2i}{dt^2} + r\frac{di}{dt} = T_c - T_o$

beyond, the order of the corresponding differential equations becomes higher and their solution more involved. The similarity between these equations and those encountered in the theory of oscillations as applied to dynamic or electrical-circuit problems has been recognised, and the process of designing a suitable control system involves manipulating the equations into a convenient mathematical form to give the desired result and interpreting this form in the design of the electronic controller.

By methods such as these it has been possible to make considerable advances in the design of control systems for many types of drives encountered in the steel industry, such as coiler motors, constant-speed drives, tension controls, reversible drives, etc. It is the aim of the electronics engineer to obtain the most elegant practical solution of any control problem, that is, the one giving the optimum fidelity with the minimum of components, having due regard to safety and stability in operation.

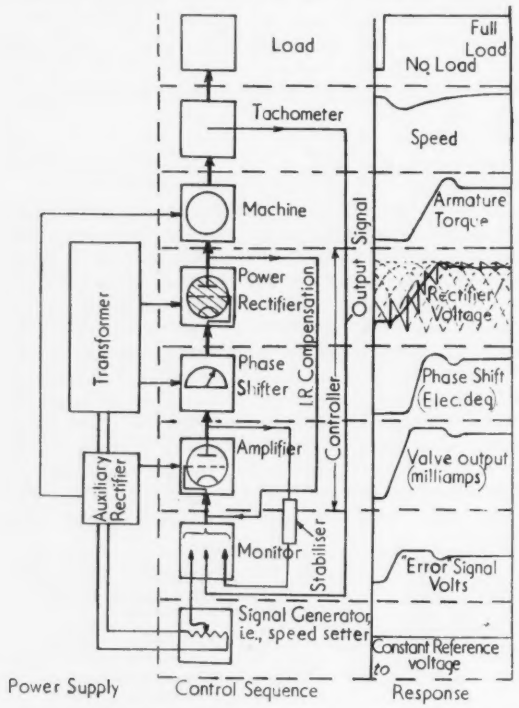


Fig. 7—Diagram showing control sequences in automatically maintained preselected speed with load varying

Analysis of a Control Sequence

To facilitate the rapid recognition of the requirements of a control sequence it is common practice to make use of "block" diagrams, in which the controller is broken down into a series of units and the power and the control paths indicated by single lines. These diagrams are of considerable assistance both in analysing the complex electrical-circuit diagrams or in building up a control circuit from its fundamental requirements and arriving at a general understanding of a control sequence. It is possible by this means to show clearly the main sequence and also the feedback and overriding safety signals necessary in a practical equipment. The stages at which the extra controls are introduced will depend upon the design of the circuit and although, in general, the electronic control loops present fewer opportunities for these additions as compared with some cascaded electrodynamic systems, novel and ingenious methods of meeting the requirements are constantly being discovered by the circuit designers. Figure 7 shows the diagrammatic treatment of a typical power-control sequence for a variable-speed drive.

An important feature of the analysis is the influence of the non-vacuum components in introducing time lags which would otherwise be absent from an electronic system. They are produced by series inductances or capacity-resistance charging circuits and also by smoothing circuits. The effect of these time lags is to retard the phase of the processed signal until it may arrive at the machine in anti-phase to the original disturbance, thus creating conditions for oscillation and instability. Fortunately, this tendency can be corrected by introducing phase-advancing circuits or by increasing the amount of negative feedback. Circuits for introducing the latter effects are shown in Fig. 8.

Some Criteria of Performance

In keeping with modern methods in dealing with control problems investigators have sought more direct methods in determining the performance of a servo system. The recognition of the similarity between these power-circuit problems and those encountered in radio amplifiers has led to performance criteria based on the study of the time constants of the system and also to the adoption of the stability criterion developed by Nyquist[10] for the treatment

of the radio type feed-back amplifier. The influence of the time constants can be seen from Fig. 9, which shows the similarity between a vector diagram for an industrial control circuit and that of a valve oscillator. The characteristic equation of a control sequence in a "position error" servo can also be given in terms of the time constants of the controller and machine as :

$$\theta_o = \frac{\frac{K\theta_i}{T_1 T_2}}{p^2 + p\left(\frac{1}{T_1} + \frac{1}{T_2}\right) + \frac{1}{T_1 T_2}\left(1 + K\right)}, \quad \ldots(10)$$

where T_1 is the time constant of the controller and T_2 that of the machine, and K is the static gain factor. The equation of the denominator is :

$$p^2 + p\left(\frac{1}{T_1} + \frac{1}{T_2}\right) + \frac{1}{T_1 T_2}\left(1 + K\right) = 0. \quad \ldots(11)$$

The "damping ratio" may be written as

$$\frac{\frac{1}{T_1} + \frac{1}{T_2}}{2\sqrt{\frac{1}{T_1 T_2}\left(1 + K\right)}},$$

and an interesting instance arises when T_1 is made equal to T_2 in which case the permissible static gain factor is zero. The gain in stability and the increase in amplification permitted when T_1 and T_2 are different are shown in Fig. 10. This is only for critical damping which is rarely used. In practice the ratio T_1/T_2 is often made equal to the gain factor and results in about 10% overshoot.

With the Nyquist criterion the response of the machine and the controller to sinusoidal input signals is examined at different frequencies, either calculated or measured directly in a practical case, and the results plotted in the form of the amplitude gain against the phase displacement for the different frequencies. This plot giving the locus of the output vector in amplitude and phase relative to the input over a range of

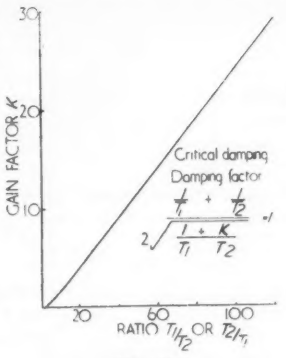


Fig. 10 Fig. 11

Fig. 10—Influence of ratio of time constants of controller and machine on gain factor with critical damping

Fig. 11—Stable and unstable "transfer loci" (Nyquist criterion)

frequency ($\theta_o\, j\,\omega/\theta$) is called the transfer locus of the system and defines completely the performance of the system. The transfer locus is plotted in polar form, as for example in Fig. 11, and for all frequencies from zero to infinity, the calculation being facilitated by the substitution of the operator $j\,\omega$ for p in the typical equations. The conjugate or mirror-image diagram is also drawn, and if these curves together enclose the point $(-1, j\,o)$ the system is unstable ; if this point is not enclosed the system is stable. The transfer locus diagram refers to the ratio θ_o/θ. The ratio θ_o/θ_i known as "Q" is also of interest, and similar and more direct methods have been used by Whiteley[9] employing the inverse ratio θ_i/θ_o to construct the inverse transfer locus diagram, an aid to the study of "Q."

By methods such as these it is possible in the design stage to predict the response of an equipment, the normal accuracy of control, and the amount of overshoot caused by sudden change, so that despite the increased number of variables introduced in the electronic control circuit the final result offers considerable improvement not only in the performance of the control but in the results of the application as compared with earlier methods.

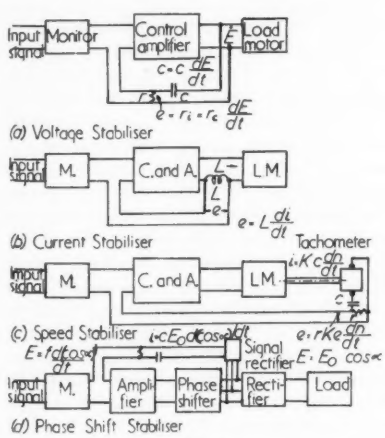


Fig. 8

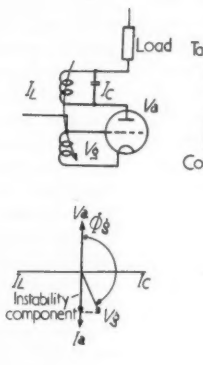


Fig. 9 (*a*)

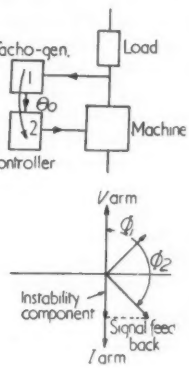


Fig. 9 (*b*)

Fig. 8—Stabilizing circuit

Fig. 9—Comparison between feed-back in valve circuit and control system. (*a*) Oscillatory condition for valve circuit: (*b*) Time-cap control system producing oscillatory conditions

STATIC POWER UNITS AND THEIR CONTROL

The mercury arc rectifier provides a convenient electronic means for the static conversion of power, particularly as the ultimate stage of an amplification process, where the introduction of control grids offers scope for the use of electronic control

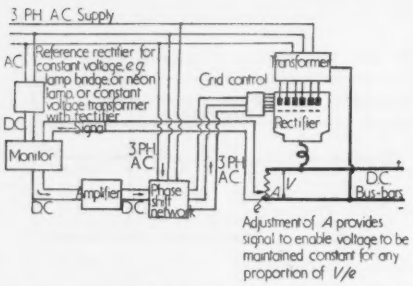


Fig. 12—Application of voltage regulation to grid-controlled mercury arc rectifier

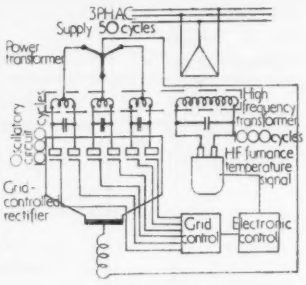


Fig. 13 (*a*)

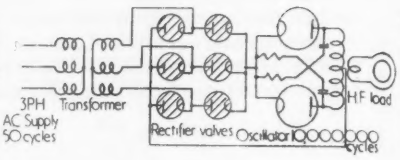


Fig. 13 (*b*)

Fig. 13—(*a*) Direct generation of high-frequency by mercury arc rectifier. (*b*) High-frequency electronic heating

equipment as well. The essentials of the plant are a phase-multiplying transformer, to give the smoothness of the D.C. output, and a mercury arc rectifier complete with its necessary auxiliaries in the form of ignition, excitation, and control apparatus and a cooling fan. There are four main types of rectifier associated with the iron and steel industry, namely, the glass bulb, the water-cooled pumped type, the air-cooled steel tank pumpless rectifier, and the single anode types. They enable advantage to be taken of the economy of A.C. transmission of electrical energy and at the same time make D.C. available at the load for supplying variable-speed machines, electrolytic loads or high-frequency oscillators for induction heating. At the same time, however, there is no "flywheel" effect and the load is felt instantly on the A.C. system. In some instances special types of mercury arc rectifier have been devised incorporating auxiliary anodes for the supply of power to field circuits, the main anodes feeding the armature with variable voltage. In all these applications the rectifiers function as synchronous switches, the anodes of the rectifier forming an electronic commutator system to the phases of the transformer. The grid-control feature may be used to maintain constant or adjust the D.C. voltage independently of supply or load variations, an important advantage where precise output control, either of voltage, current, or power, is required. It can also be used to enable the rectifier to function as an inverter and feed-back to the A.C. system. Figure 12 shows an example of an automatic voltage regulator of the electronic type, as applied to a grid-controlled rectifier; a scheme adopted for the supply of power to rolling mills is mentioned in a later example. Figure 13 (*a*) illustrates the direct use of a mercury arc rectifier for generating high-frequency oscillations for induction furnace work at about 1000 cycles/sec., and Fig. 13 (*b*) shows a type of electronic circuit used for high-frequency heating at about 1,000,000 cycles/sec.

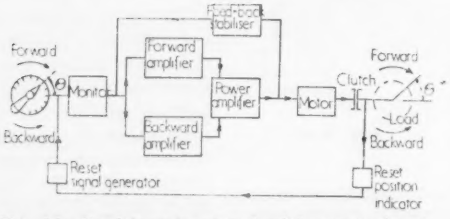


Fig. 14—Positioned control with reset circuit

ELECTRONIC LIMIT SWITCHES, COUNTERS, AND TIMING CONTROLS

Electronic Limit Switches

The natural form of electronic limit switch or counter is the photo-electric cell in which a beam of light directed to the cell is interrupted by the object under control or the cell is actuated by the heat radiated from the object itself. The amplified signal from the cell is passed to the electrical or electromechanical control. A typical example of this type of control as used in a steelworks is the handling of hot strip for welded steel tubes at 1350° C. After passing through the sizing rolls the tubes run at a considerable speed down a trough and are automatically transported to cross rolls, moved to a cooling tank, and finally dropped on to a collecting cradle. The hot tubes follow one another longitudinally at a few seconds interval, with about three feet spacing. Mechanical timing devices are subject to wear and have proved unsatisfactory for avoiding collisions between tubes. Photo-electric cells, illuminated by the heat from the tube and operating the control shutters through amplifiers and relays, have proved an efficient method of timing and can withstand the high temperatures and the vibrations of tube-mill work. In addition red and green lights operated from the cells indicate to the operators whether the line is clear or blocked. Other applications of a similar character are the actuation of rod-mill shears and the clearing of the work from run-out tables. Somewhat different is the stopping control on centrifugal-casting machines which operates when the metal has reached a predetermined cooling temperature.[11]

By means of photocell temperature recorders provision can be made for testing the actual temperature of the strips leaving the furnace. Similar apparatus has also been used to measure the temperature of the billets before rolling, and the temperature may be read on any of four meters covering a wide range of alloy steels. The reading on a photocell may also be used to control the temperature of the furnace either by direct radiation method or colorimetry of the flame, or to determine the speed of transit of the steel through the furnace, or to regulate the automatic

gas control on pipe-welding processes. In these cases the control is the equivalent of a closed loop system, but the time constants of the furnace and of the recording gear are so widely different as to be inherently stable. The design of the equipment is such that there is no difficulty in housing the gear suitably for a steelworks atmosphere.

Counting Devices

Counting operations are easily carried out by attaching an electronic counter using two or more gas-filled valves, operated by a photocell, and driving a recording gear; by this means fast and accurate counting is attainable under the worst conditions and it has been applied to sheet counters on shearing lines.

Timing Controls

Electronic timing controls have had considerable application particularly in connection with spot and seam welding, where devices of the ignitron type are used. The circuits have been frequently described in the wide literature on the subject and need only passing reference here. There are very many different forms of timing relays; the simple variety is based upon the time taken to charge or discharge a condenser through a resistance, or the charging current in an inductive circuit, the circuits being controlled by neon lamps or vacuum or vapour valves. By these means time delays of from 0·5 sec. to several minutes may be obtained. Variants include cascaded circuits, in which the first stage operates a number of times to complete the charging of the second, or bi-metal strips with added thermal capacities may be used in conjunction with valve circuits for controlling process times or other operations.

POSITIONAL CONTROL

This type of control is available in electronic form for industrial applications covering a wide range, to meet the general requirement that the particular machine under control shall take up, with accuracy and without delay, the position or setting communicated from an external source. Controls of this kind are popularly referred to as "R.P.C." and are capable of being developed to an accuracy within ½% and a time delay of a few milliseconds. The principle of this type of control is illustrated by the block diagram Fig. 14, although there are several different methods of putting it into practice. The essence of the scheme is a forward and reverse channel, either being brought into operation according to the message received from the signal generator. The difference in the applications lies in where the channels divide and combine again, whether they shall remain divided up to the mechanical stage actuating forward and reverse motors, or be combined at the motor in a two-fold system or combine at a direction-conscious power amplifier, of the type illustrated in Fig. 4, to actuate a standard type of motor. The stabilizing signal or negative feed-back is usually tapped off between the power amplifier and the motor and is taken to the output side of the monitoring device. In certain cases it is required to insert a rendering device or slipping clutch in the mechanical system, in which case a "re-settler" circuit is also necessary to correct the relationship between the load and the remote-control circuit, as shown in Fig. 14, this circuit coming from a signal generated at the load to the input side of the monitor.

Electronic positional controls[12] are suitable for such applications as screw-downs and manipulators on a reversing hot mill, synchronization of mechanical movement in handling equipment, contour following (which may be automatic, through the use of a scanning or traversing system, to enable the signal generator to be actuated by a profile cam or model shape), or maintenance of constant pressures in press work. In some instances there are advantages in incorporating the light current technique of using a modulated A.C. carrier frequency in place of the usual D.C. or 50-cycle A.C. signal channel.

The setting of two photocells to react in the event of deviation from a mean position enables a form of "on–off" control to be devised to hold a control element within close limits, or alternatively, to regulate the level of a charge in a hopper. The control element may be used to regulate the gas mixture for a furnace, control a strip-traversing machine or a line-following device for cutting steel plates either from a template or a line chalked directly on the plates. The same principle can be applied with greater accuracy by using a light-splitting device, such as two 45-degree prisms, to provide a continuous control signal in terms of the proportion of the beam diverted to a photocell on either side.

An alternative method of producing a positional control is to use a phase-conscious amplifier in combination with a magnetic bridge such that a deflection to one side causes a controlling response proportional to the deviation and in the sense required. Gear of this kind has been applied for actuating forward and reverse motor controls for regulating the speed of large motors.

Another example of positional control concerns the electronic regulation of the electrodes in arc furnaces, in which the control is provided by balancing the

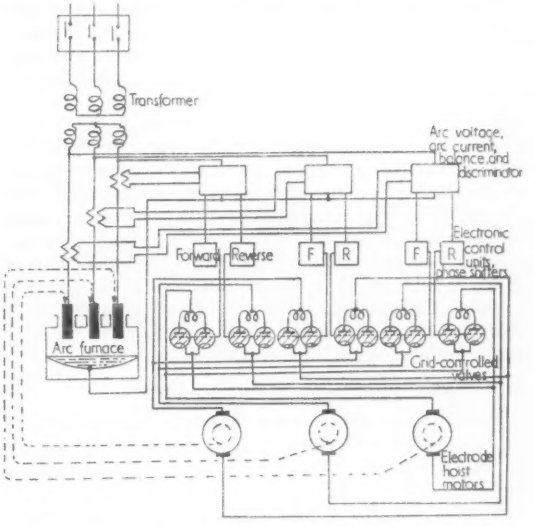


Fig. 15—Arc-furnace control with electronic position control of electrodes

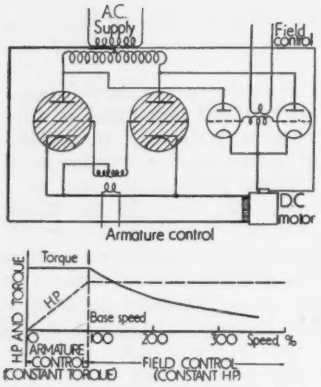


Fig. 16—D.C. motor electronically operated from A.C. supply

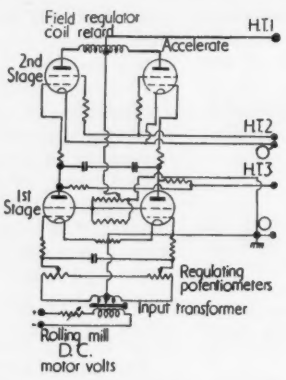


Fig. 17—Electronic control for take-up-reel motor of strip mill using two-stage push-pull amplifier

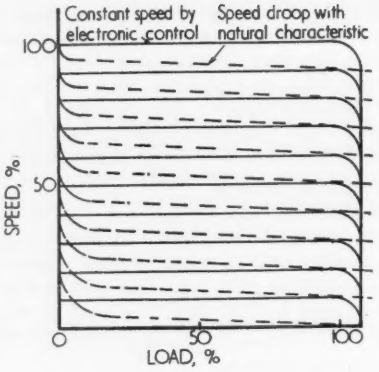


Fig. 18—Improvement in preset constant-speed drive by electronically controlled rectifier supplying a D.C. motor

arc voltage against the load current, as shown in Fig. 15.[13] Amongst other applications of photocells to rolling mills are the device for locating precisely the edge of the coil being rolled, to produce a coil with smooth ends, or the servo control to maintain the correct amount of sag in a loop between stands or, similarly, to control the loop in strip-processing lines.

ELECTRONIC SPEED CONTROL

The problems associated with electronic speed control are, as already indicated, inertia, friction, and power control, and the electrical losses in the machine and the reaction of the load. Although it is common practice to combine the properties of pre-set constant speed, speed adjustment, and reversibility in one unit, these requirements are also met with independently and will, therefore, be discussed separately and an example given of their combination.

Constant Speed

There are a number of methods including armature control or field control or a combination of both. For all but the smallest powers the use of mercury arc or hot cathode rectifier is necessary, as indicated in the basic circuit of Fig. 16. Where the characteristics of the load are known the constant speed may be attained by a combination of IR drop compensation and compounding, and an accuracy of about 5% can be maintained. Amongst many applications of this are draw benches for tubes and conveyors. Greater accuracy, to within 1%, requires a constant reference scheme incorporating a complete servo system. Drives of the latter type have been used in connection with machine-tool feeds and power rams where the time delay in emptying a hydraulic cylinder can be avoided and a rapid reversal achieved.

Variable-Speed Drives

These are usually carried out by a combination of armature and field control, using constant torque up to full armature voltage and constant horse-power beyond that to full speed. By this means speed ranges of 100 to 1 are attainable. Because there is as yet no electronic torque converter the machine has to be of a frame size to give both the maximum torque and the maximum speed, the equation of speed control being :

$$n = \frac{V - RI}{N}, \quad \text{.....(12)}$$

where n = speed, V = armature voltage, R = armature resistance, I = current, and N = flux.

One of the best examples of a variable-speed drive in the steel industry is the coiler motor on a continuous strip mill. The general requirement that the speed shall be inversely proportional to the coil radius, is met by controlling the motor at constant horse-power, but the maintenance of correct tension is more critical and equipment has been installed at different plants in South Wales[14] to keep an even tension on the strip as it leaves the last stand in a multi-stand mill by controlling the speed of the take-up-reel motor through field control. The basic circuit due to G. E. Davis and S. A. Emms is shown in Fig. 17, and comprises a transformer connected across the main motor armatures, the transformer secondary actuating an amplifier which in turn controls a current regulator for the field of the coiler motor. Any change in mill speed produces a flux change in the transformer, and the secondary voltage thus induced gives a signal to the amplifier in the correct sense according to whether the coiler requires accelerating or retarding in response to any change in speed of the main drive, and thus maintains an even tension in the strip.

A kindred problem in variable speed arises in maintaining the correct radial feed across a large surface such as the faceplate of a lathe or the table of a boring mill, where the speed of rotation or the feed has to be adjusted to keep the rate of cutting constant to enable the work to be turned out in the minimum time and with a uniform finish.

An important aspect of variable-speed drives is the provision for inching speeds for adjustment or threading. In this connection the electronically controlled drive presents advantages because of its ability to cope with voltage-drop compensation and line-voltage variation. Without the level compounding at all speeds the proportion of voltage drop increases as the voltage is reduced, as shown in Fig. 18, and changes of speed with torque are sudden and even erratic.

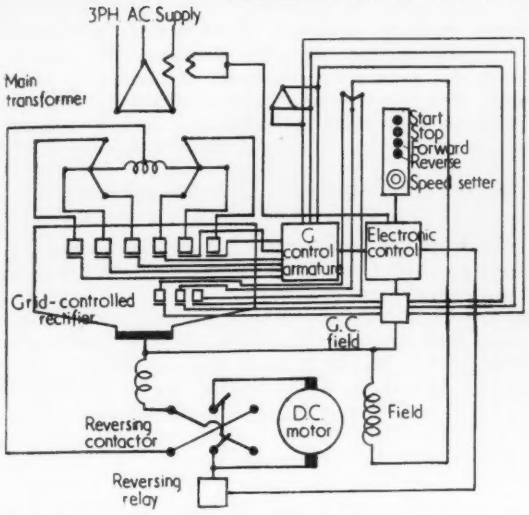


Fig. 19 (*a*)—D.C. motor drive with electronic control and armature-current reversal

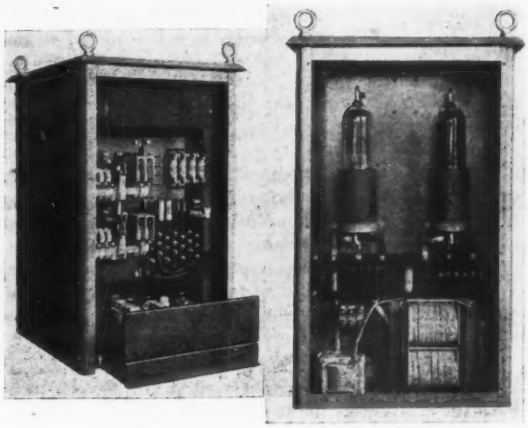


Fig. 20 (*a*) **Fig. 20 (*b*)**

Fig. 20—Small motor control unit showing (*a*) chassis-mounted electronic control and panel-mounted reversing contactors, and (*b*) grid-controlled mercury vapour valves for armature supply

With electronic control correcting signals can be introduced in the amplifier completely to compensate these effects and permit a stable and controlled crawl speed and a smooth acceleration. This is a valuable feature in dealing with strip rolling where successive lengths are joined by welding to save threading.

Reversible Drives

The direction of rotation of a D.C. machine can be changed either by field or armature current reversal, but a rectifier can only pass current in one direction, so that when the direction of power flow has to be changed it is necessary either to reverse the connections to the load or to have a second rectifier standing by reversely connected. There are, therefore, three methods of obtaining reversal; first, by using reversing contactors to change the motor armature connections. This is of necessity confined to small motors, as the kinetic energy of the system has to be dissipated in the windings of the machine. The second method is to apply arc suppression to interrupt the current flow by means of the grids of the rectifier, change over the contactors while no current is flowing, adjust the phases of the grid impulses so that on release the kinetic energy of the system is regenerated into the A.C. supply, and, finally, advance the grid control so that the motor is brought up to the desired speed in the new direction. It is in this technique that electronic control has been found extremely valuable in increasing the precision of the sequence, the speed of changeover, and in preventing excessive current during regeneration. It is of interest to note that the regenerative feature, during which the rectifier functions as an inverter, can be applied to field control to force the rapid reversal of the field without the appearance of excessive voltage. Figure 19 (*a*) illustrates the application of this method to rolling-mill drives using armature current reversal, and Fig. 19 (*b*) indicates the field-reversal method. Figure 20 illustrates a small unit incorporating all three features of constant pre-set speed, speed control, and controlled reversal

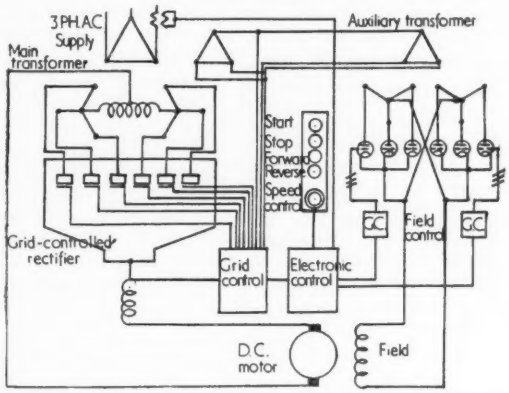


Fig. 19 (*b*)—D.C. motor drive with electronic control and field reversal

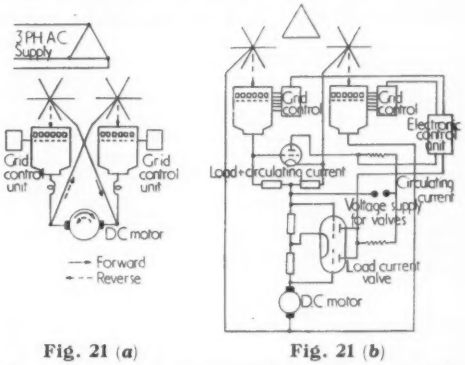


Fig. 21 (*a*) **Fig. 21 (*b*)**

Fig. 21—Rectifier inverter circuit for contactorless motor reversal. (*a*) Motor reversal by "figure of eight" circuit using rectifier inverter pair; (*b*) Electronic control of "figure of eight" circuit by circulating current methods

with full protection against overloads in all circumstances.[15] Larger units have been built for planing drives ;[15] an equipment has been installed in Birmingham for a 5-ft. × 5-ft. × 14-ft. planer driven by a 50-h.p., 480-V. motor supplied by an electronically controlled grid-controlled mercury arc rectifier which automatically adjusts its phase and operates as an inverter to permit regeneration during the slowing down period, and has shown the advantages of being able to save space by mounting the gear on a light gantry and of considerably improved commutation on the machine motors as compared with conventional Ward-Leonard drives. The methods of feed selection and control generally show a considerable advance when compared with earlier machines.

Thirdly, where very large powers have to be reversed with absolute control, no " dead period," however short, allowed for switching the so-called " figure of eight " circuit, is used, as shown in Fig. 21 (*a*). In this arrangement a rectifier inverter pair is incorporated. The circuit has been applied some years ago, although without the refinement of static phase shifting, to pit winders[16] and planing machine drives,[17] and would be applicable to skip hoists or reversing slabbing mills. A method of applying electronic control, indicated in Fig. 21 (*b*), is based upon the maintenance of a predetermined amount of circulating current between the rectifier and the inverter to ensure the transfer of load without a sudden voltage change.

The advantages of electronically controlled variable speed drives accrue to the mechanical system, the electrical circuit, and the material in production. First, there is reduced wear and tear on the control devices because of the smoother operation ; secondly, a reduction in the wear and tear on the mechanical equipment due to the smoother operation of the control giving a steadier application of torque ; thirdly, the current on starting up and reversing is limited and applied correctly ; fourthly, there is the immediate cut off of power in the event of trouble ; fifthly, the uniform torques permit higher accelerations, speeds, and retardations, and provision for applying predetermined overvoltage without risk of damage ; and finally, the consistent performance will ensure uniformity of the product.

Many of the R.P.C. applications noted in the previous sections have their corresponding variable-speed features such as screw-downs, side-guard manipulators, live tables for blooming mills, shears, hot-metal saws, etc. Similarly, the following types have their counterparts in speed-following arrangements to co-ordinate the working of different sections of a plant, such as the edge rolls in a slabbing mill.

MULTI-UNIT DRIVES AND SIMULTANEOUS CONTROL

These are the latest types of electronic drives which are being tried out in connection with multi-stand tandem mills and grouped fan drives, they are also applicable to continuous oven working and mixture controls on conveyor-belt work. There are two possibilities, one, Fig. 22 (*c*), is to gang all the armatures of the motors to be controlled on to a common bus-bar system and to control the voltage of the bus-bar so that all the motors change speed in proportion, the individual speed ranges and trimming if necessary being affected by additional individual field control. The second method, Fig. 22 (*b*), is to supply each motor separately from its own grid-controlled rectifier and gang the rectifier controls. The advantage of the former method is that it enables advantage to be taken of the diversity factor in the loading of the plant, whilst the latter prevents the possibility of very large currents circulating between the machines under faulty conditions. With this second method there is also the possibility of introducing a differential system of control on the last pair of rolls, to counteract the tendency of the gauge of the sheet to change during acceleration and retardation, thus producing a greater length of standard thickness in each coil of strip.

An example of grid-controlled rectifier application is provided by an installation in a South African steel mill in which a 4000-h.p. mill motor is run up to speed by a 6-cylinder, 12-phase, pumpless steel tank mercury arc rectifier equipment. The principle is being extended in an equipment now under construction for the Steel Company of Wales. The finishing mill of the new continuous hot-strip mill under construction is to be supplied from a steel tank pumpless rectifier group of 21,000 kW. capacity at 800 V., D.C. It will be arranged in 10–6 phase groups operating as a whole, and the equivalent of 60-phase rectifier alternating current will be practically a pure sine wave. In order to eliminate fluctuations of relative speed of the different mill motors all the rectifiers feed into a common D.C. bus-bar, from which the six mill motors will be supplied. The D.C. bus-bar voltage will be held constant, irrespective of the normal voltage variations of load and A.C. supply voltage, by grid control of an electronic voltage regulator. Grid control will also be used over a wide range for inching and starting.

An earlier example of the unit-drive arrangement is provided in the 5-stand mill for continuous hot-strip rolling installed in Western Germany. This equipment consists of five

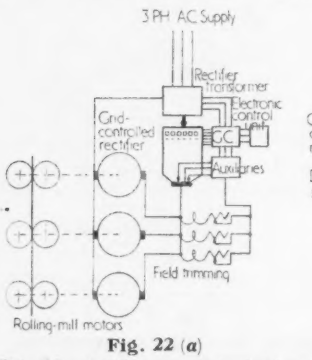


Fig. 22 (*a*)

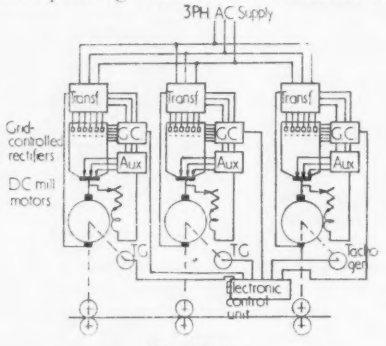


Fig. 22 (*b*)

Fig. 22—(*a*) Group control of rolling-mill motors from grid-controlled rectifier. (*b*) " Unit drive " for rolling-mill motors with ganged controls and electronic master control

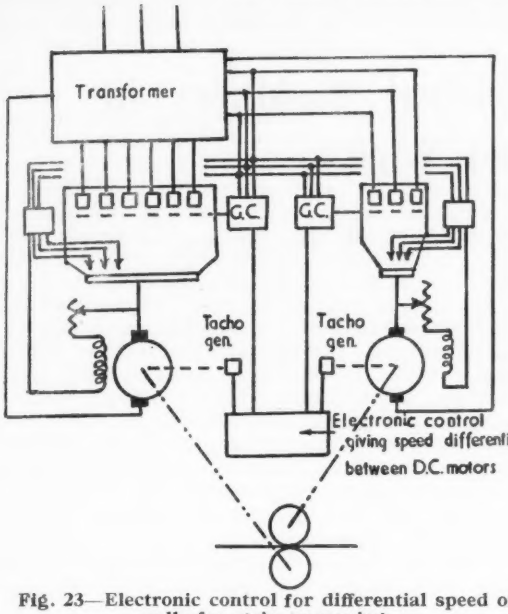


Fig. 23—Electronic control for differential speed of rolls for strip tempering

motors, each supplied by a 2400-kW. water-cooled rectifier, with grid control as the main speed control and manual control for field trimming.

Electronic methods provide a convenient means of achieving a differential speed control between two pairs of rolls, as shown in Fig. 23 ; similar equipment is already being tried out in America in connection with a uni-temper mill.[18]

REMOTE CONTROL

The experimental application of electronic control to crane drives, in the form of the control of drives incorporating electromagnetic eddy-current brakes and clutches, has already been carried out.[19] The possibility of remotely controlling cranes in a stock-yard by methods based on the use of a radio link, with a carrier frequency particular to each crane has also been mooted. Similarly, proposals have also been made to utilize the ripples produced from a rectifier output as a means of selective switching in combination with tuned shunts responsive to the appropriate frequency and a corresponding tuned relay at the automatic controller, to bring the desired control into operation. There is scope for considerable development on these and similar lines.

ECONOMIC CONSIDERATIONS

Now that increasing experience is being gained with industrial applications of electronics it must be admitted that the first cost of control schemes is comparatively high for small powers, mainly because the advantage of the low cost of the valves and other components produced as a by-product of the radio industry is off-set by polyphase circuits and the manufacture of other components to engineering standards. For large plants the capital cost of the control equipment is a much lesser proportion of the total, the use of mercury arc rectifiers enables many economies in installation and running costs to be effected in all except a few cases where full reverse power requires duplication of plant.

Comment has already been made on the reduced time of operation and the convenience of working, whilst the security and precision in handling when once experienced are not easily set aside. Skilled operatives are quick to take advantage of such ease of control and are often able to produce an increase in output in excess of that anticipated. It has also been found that in most cases the reliability of the electronic part of the system is better than that of the mechanical features, due to its static nature, ease of mechanical housing, high-speed electrical protection, and absence of mechanical loading.

SUMMARY AND CONCLUSIONS

Electronic control represents the combination of electrical engineering, mechanical engineering, and radio technique. So far as the iron and steel industry is concerned only the threshold of the applications of electronic control has been reached, but there is no doubt that the introduction of this technique will enable the standards of control to be raised to new high levels which should ultimately prove of great benefit to the industry and all who work in it.

Acknowledgments

The author wishes to acknowledge his indebtedness to the General Electric Company, Ltd., for permission to publish this paper, the co-operation and assistance of his colleagues, and the kindness of the British Thomson-Houston Co., Ltd., and Messrs. Metropolitan-Vickers Electric Co., Ltd., in providing information about their equipments.

References

1. H. A. Thomas : *Journal of the Institution of Electrical Engineers*, 1947, vol. 94, p. 309.
2. W. G. Thompson : *Transactions of the North East Coast Institution of Engineers and Shipbuilders*, 1946, vol. 62, p. 73.
3. J. P. Girard and G. D. Adams : *Transactions of the American Institute of Electrical Engineers*, 1946, vol. 65, pp. 241-246.
4. G. R. Polgreen : *G.E.C. Journal*, 1947, vol. 14, p. 167.
5. A. L. Whiteley : *Journal of the Institution of Electrical Engineers*, 1947, vol. 94, p. 5.
6. A. Tustin : *Ibid.*, 1947, vol. 94, p. 532.
7. W. H. Sykes : *Institution of Electrical Engineers Students Quarterly Journal*, 1947, vol. 18, p. 32.
8. G. S. Brown and A. C. Hall : *Transactions of the American Society of Mechanical Engineers*, 1946, vol. 68, p. 503.
9. A. L. Whiteley : *Journal of the Institution of Electrical Engineers*, 1946, vol. 93, p. 353.
10. H. Nyquist : *Bell System Technical Journal*, 1932, vol. 11, p. 126.
11. J. H. Hopper : *Year Book of the American Iron and Steel Institute*, 1943, p. 312.
12. E. W. Forster and L. C. Ludbrook : *Journal of the Institution of Electrical Engineers*, vol. 94, p. 100.
13. H. G. Fostick : *Westinghouse Engineer*, 1945, vol. 5, p. 188.
14. *G.E.C. Journal*, 1945, vol. 13, p. 118.
15. *G.E.C. Journal*, 1947, vol. 14, p. 135.
16. W. Leukert : *Electrotechnische Zeitschrift*, 1937, vol. 58, p. 527.
17. E. Koncar : *A.E.G. Mitteilungen*, 1939, vol. 2, p. 65.
18. J. C. McCurley and J. D. Campbell : *Year Book of the American Iron and Steel Institute*, 1946, p. 584.
19. G. B. Sadler : *Journal of the Institution of Electrical Engineers*, 1948.

The Maintenance of Electrical Machinery in Iron and Steel Works

By G. S. Martin, A.M.I.Mech.E., A.M.I.E.E., and M. Y. Harvey, A.M.I.E.E.

ALTHOUGH the general principles of maintenance are fairly obvious, it may be desirable to run over them briefly. Strictly speaking, the maintenance engineer should not be satisfied until he has completely eliminated breakdown due to faulty or inadequate maintenance, and has done this at the lowest possible cost. Although the imperfections of humans and machinery make this practically impossible, a great deal can be achieved by effective planning together with a serious effort on the part of management and men to carry the plan through.

It is the purpose of this paper to indicate some of the methods employed in endeavouring to reach the highest standard of efficiency, and whilst it is quite impossible to cover the subject in detail some actual examples have been chosen by way of illustration. It is also probably true to say that if less stress were placed on initial expenditure, and consideration was given mainly to the suitability of plant and plant lay-out for steelworks duty, the job of maintenance would be considerably simplified, and the loss of production through breakdown consequently reduced.

The results of haphazard maintenance or no maintenance at all are only too apparent in some of the older plants, and the condition of this kind of plant now is largely responsible for much of the production time lost.

There will of course always be breakdowns because, apart from the need for maintenance, there are many other contributory factors, some of which will always be with us. For this reason it is of paramount importance that the maintenance department should be well equipped, and well organized to ensure that breakdowns are quickly and expeditiously handled.

ORGANIZATION

The organization will vary to some extent in each works, these variations being due to the different plant lay-out, local conditions, type of skilled and unskilled labour available, etc.

Firstly there will be an electrical engineer in charge of the electrical maintenance, and he should preferably be a man with both practical and technical knowledge and possess a high degree of organizing ability and efficiency. His work can be divided broadly into five sections : outside maintenance, electrical repair shop, power stations, instrument repair and calibration, and plant reconditioning. He will require assistants of some kind, and in a large works he may need a personal assistant of his own calibre, but in smaller works his immediate assistant may be a foreman. It is difficult to set any standard regarding the number of foremen for the works, but there will probably be one or more foremen on outside maintenance and one in the repair shop. Under the foremen, on outside maintenance, will come skilled and unskilled men who are placed according to the requirements of the plant.

A foreman will also be necessary for the electrical repair shop, where it is his duty to attend to the day to day running of the shop. In this department there will be various types of tradesmen, such as electricians, winders, turners, fitters, apprentices, labourers, and possibly storemen.

Power stations are usually manned by skilled attendants or steam-service men with semi-skilled assistants ; these men become so familiar with their machines and equipment that no special supervision is necessary.

The same applies to the meter department, where one or two meter mechanics can normally handle routine checking and repair work, and still have time for experiment and investigation.

The decision to have a squad on plant reconditioning depends, of course, on the age and condition of the plant. If the plant is not new and is run with the minimum of men it is difficult to overcome some of the major jobs such as relaying main cables, installing modern control gear, and undertaking the complete re-wiring of cranes. Our experience has been that the best way to tackle such a problem is to delegate it to a special squad free from all other duties. This squad may consist of a foreman or leading electrician, two or three electricians, and two labourers. It is surprising how much work this small number of men can cover when their efforts are concentrated on particular jobs. The results obtained from this scheme, and the relief given to the maintenance electricians, have convinced us that it is sound policy.

It may be of interest, however, to give some details of the electrical maintenance organization at one particular works in which there is a meltingshop with seven 90-ton open-hearth basic furnaces of which six are usually in operation, producing between 6000–7500 ingot tons per week of 19 shifts. There are also three steam-driven rolling mills, a 42-in. cogging mill, a 34-in. billet mill and a 32-in. section mill, between them producing about 6000 tons of finished output per week of 17 shifts. In addition there is a

Manuscript received 10th March, 1948.

Mr. Martin is with The Lanarkshire Steel Co., Ltd., Flemington.

Mr. Harvey is at Colvilles, Ltd., Glengarnock.

plant which produces 400–500 tons of sleepers or 120 tons of fishplates, and 120–140 tons of baseplates per week of 6 shifts. The electrical plant is entirely D.C. all of which is generated inside the works by mixed-pressure turbo-generators. There are three of these sets, two of 2500 kW. and one of 1500 kW., and normally one 2500-kW. set and one 1500-kW. set run in parallel to meet the day-time load. The total number of motors in service is approximately 650, and the total motor horse-power is approximately 21,000. Figure 1 is a chart giving details of the manning for this steelworks, and reference to this chart shows that there are two shift foremen who organize and deal with the maintenance and breakdown work and are also responsible for the supervision of the electric overhead crane drivers.

The plant is divided into two main sections, as shown, and the shift electricians are each responsible for the repair of breakdowns on all equipment in their section, and for routine maintenance each is responsible for a due proportion of the equipment in his particular section.

The plant fitters who are employed only on dayshift are responsible for maintenance and preparation of spares, but they also assist at breakdowns, when necessary during their shift, and are on call at any other time if their services are required. Lamp men, who are semi-skilled, are responsible for the replacing of lamps and for repairs to lighting fittings, etc., throughout the works and, in addition, each is responsible for the cleaning of a certain number of lamp fittings. The motor oiler attends to the lubrication of all motors throughout the works, excluding those on electric overhead cranes. Generally speaking, the arrangement works well, and considering the fact that the plant operates intensively and much of it is fairly old, the number of breakdowns for which the electricians can be held responsible is fairly low.

It is generally admitted that some form of systematic plant inspection and recording is desirable, although there is some controversy as to how it should be carried out. At the works mentioned, this inspection is done by the section electrician, and a time limit is fixed for the inspection of each part of the equipment he is required to maintain. Records are kept of all repair work done by each man, and reports are submitted to the shift foremen noting items requiring attention. These foremen supervise the work of the men to ensure that the inspection is efficient and effective, and any repairs which may be required are carried out as quickly as possible. This system has given satisfactory results.

On another plant of somewhat similar size the method adopted has been to place a man with practical and some technical knowledge in charge of both mechanical and electrical inspection. He works to a definite rota, the time intervals being based on trial and error, and on his inspection he takes with him the shift engineer or shift electrician responsible for the particular portion of the plant which he is examining. Minor items are attended to immediately, but anything else is entered on a card-index system which is scrutinized by the foreman and chief engineer.

A further important function of the organization is to cover for temporary work done and, if steps are not taken to meet this, the number of temporary jobs in the works can mount up alarmingly. Various methods of tackling this may be used and a simple form of report book in which all temporary repairs are noted is as good a way as any of keeping track of events.

Nothing much need be said about organization of the electric repair shop since most of these are probably run on somewhat similar lines. It is essential, however, that a high standard of workmanship be attained and that every effort be made to meet the requirements of the outside maintenance staff.

ROUTINE MAINTENANCE

Steam Turbines

Steam turbines should be opened at regular intervals for inspection, the intervals depending on various factors such as availability, machine design, and steam conditions. For example, mixed pressure sets using exhaust steam from rolling-mill engines usually require to be opened up after 8000–12,000 hours' running, for the cleaning of blade passages reduced in area by caked cylinder oil. It is, however, advisable to open all sets after about the same period of running, even although on many of these occasions little in the way of repair may be required. During such inspection it is desirable to examine the inlet edges of the blade shrouding for rubbing marks which, although the axial blade clearances are correct, can occur, and if they do it is better to seek advice from the manufacturer. Cylinder joints should be checked for signs of short circuiting between adjacent stages, glands should also be examined for signs of

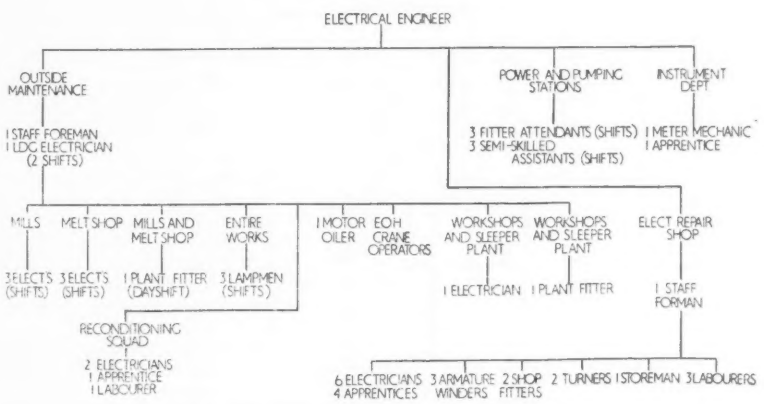


Fig. 1—Electrical-maintenance organization

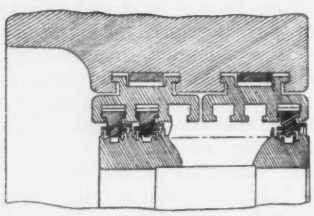


Fig. 2

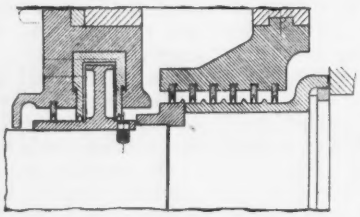


Fig. 3

Fig. 2—Labyrinth gland
Fig. 3—Water-sealed high-pressure gland

rubbing on the shaft, and water glands for wear and tear usually caused by hard or impure water.

Bearings should be examined carefully, particularly around the contact zone, and at the same time thrust clearance should be checked. Also, examine bearings for pitting possibly due to eddy currents in the rotor shaft, and at the same time test the insulation under the pedestals. Governors should be examined for signs of excessive friction and wear of pins and bushes, since these factors can upset the sensitivity, and on mixed-pressure sets can cause excessive valve chattering. For example, on a 2500-kW. mixed-pressure set the valve gear was not responding to load changes as it should and the valves were chattering badly on their seats. An examination of the governor revealed that there was excessive friction at the main side-lever fulcrum-pin bearings, apparently caused by inadequate lubrication. These bearings were splash lubricated, and by leading a small oil pipe, fed from the pressure system, to each of them a considerable improvement has been effected.

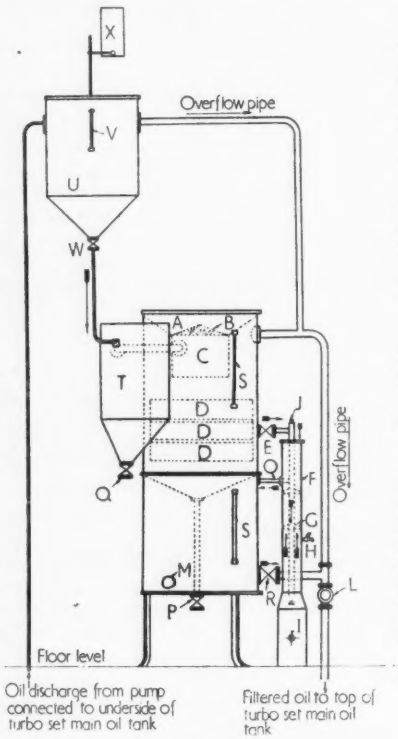
Governor valves should be examined for signs of erosion and corrosion of the faces and for excessive or uneven wear of the spindle and guide keys.

An interesting example of gland trouble revealed during inspection of a mixed-pressure unit operating on high-pressure steam at 150 lb./sq. in. at 500° F. and exhaust steam from the rolling-mill engines at a mean pressure of 3 lb./sq. in., might be worth while mentioning briefly. This set is water sealed at the low-pressure end and was steam sealed at the high-pressure end until recently, when a change-over was made to water sealing. After approximately 8000 hours' running from the date of commissioning the set, inspection revealed that corrosion of the high-pressure gland, of the design shown in Fig. 2, was developing. The fins on the spindle were badly corroded and the packing strips were rusted into the gland housing. The gland was cleaned as well as possible before closing the set, and a later inspection after a further 8000 hours' running revealed that the same condition had arisen except that the corrosion was more advanced, the tips of some of the fins being completely eaten away. The conclusion was reached that the rusting was caused by wet steam, due to protracted running of the set on low-pressure steam, at which time the only steam withdrawn from the high-pressure main was steam for the gland.

The gland was originally made of mild steel, and the question of providing a suitable alternative material, such as stainless steel, which has good erosion and corrosion resisting properties, was raised with the manufacturers, but the view was expressed that it was doubtful whether a suitable material could be provided which would be permanently satisfactory. In view of this a decision was made to convert to water sealing, as shown in Fig. 3, and it remains to be seen whether this is likely to be permanently satisfactory.

In many years working there has been no serious trouble with the nozzles or rotor blades, and this may be put down to careful manufacture in the first place and, secondly, to the use of water-treatment plant for the feed water to the boilers.

Regular attention to turbine lubrication is required, and it is advisable to have the oil tested after every period of 8000 hours' running, although when the oil deteriorates more frequent tests will be required. Periodical filtering should also be carried out, and one method of continuous filtration, given in Fig. 4, in



A—Dirty-Oil Settling Tray
B—Perforated Cap
C—Cylinder Packed with Special Filter Waste
D—Tubes Packed with Special Filter Waste
E—Filtered-Oil Discharge to Water Column
F—Water Column
G—Perforated Zinc Cones
H—Water-Level Tap
I—Flushing Tap
J—Screwed Plug for Filling to Water Level Tap "H"
L—Bulls-Eye Sight Feed
M—Draw-Off Tap for Filtered Oil
O—Filtered-Oil Inlet from Water Col. to Container
P—Sludge Cock
Q—Drain Valve
R—Filtered Oil Cock
S—Gauge Glasses
T—Settling Tank
U—Feed Tank
V—Gauge Glass
W—Dirty Oil to Settling Tank "T"
X—Float-Operated Switch Controlling Oil-Pump Motor

Fig. 4—Continuous oil filter

use on a set having a capacity of approximately 260 gal., has given satisfaction. When the filter was purchased the original intention was to feed it from the pressure side of the system, and to allow the filtered oil to drain to the settling tank, but later the decision was made to pump it from the bottom of the settling tank, for the purpose of circulating oil which usually lies stagnant. The whole charge of 260 gal. is filtered once a week, and the small motor-driven pump which is controlled by a float switch in the filter overhead tank, uses only 1 unit/week in the process. The entire charge of oil after 12,000 hours in service is in good condition, and is expected to last for a considerable time yet.

Generators, Alternators, and Rectifiers

To prevent the accumulation of carbon-dust deposits in the windings, main generators and driving motors should, where possible, be cleaned once a week by blower or vacuum cleaner. The machine should be " meggered " immediately after every shut down, and readings should be noted in the station log book so that any deterioration in the insulation resistance to earth can be investigated and rectified. The commutator and brush gear on large D.C. machines probably require as much, if not more, care and attention than any single feature of any other type of electrical machine. There may be anything up to 600 brushes on one large commutator, and it is very necessary to carry out an examination once a week, and to make sure there are no discoloured segments in the commutator, sometimes the first indication of trouble. Once a week all brushes should be examined for wear, for chipping at the edges, and to ensure that they are free in the boxes. New brushes, when fitted, must be very carefully bedded, and the whole of this routine must be carried out with close attention to detail, otherwise negligence may lead to considerable and costly brush and commutator trouble.

Every six or twelve months the machines are thoroughly examined for signs of defects, such as faulty connections, loose bolts, etc. Those parts of the machine windings which are visible should also be examined. The micas are undercut if required, and if the power station is not thoroughly isolated from the ingress of grit and dirt, the commutator may require periodical turning or stoning, and in such conditions it is also desirable to check bearing wear.

An interesting although serious instance of commutator trouble experienced on two 2500-kW. generators of exactly similar design has been undergoing investigation since the sets were commissioned, one 6 years ago, and the other 4 years ago. After the former machine had been in service for a few weeks it was observed that scoring of the commutator was developing and, despite efforts to check it, the condition became steadily worse until finally hand stoning had to be carried out. Shortly afterwards, the same condition reasserted itself and, on commissioning the second machine, similar trouble was experienced with this commutator. Investigations were then commenced in conjunction with the manufacturers. Rubbings of the commutator surface were taken, and it was found that the grooved tracks coincided with the positions of the lubricating brushes arranged on the commutator, as shown in Fig. 5. The decision was, therefore, made to remove the natural-graphite lubricators and to fit electrographitic brushes of the same grade as the rest of the brushes. This was done, and the commutator of the older machine was diamond turned while that of the other machine was hand stoned. Within a week or two the commutator on both machines for the first time developed a good skin, and it appeared as though the problem had been

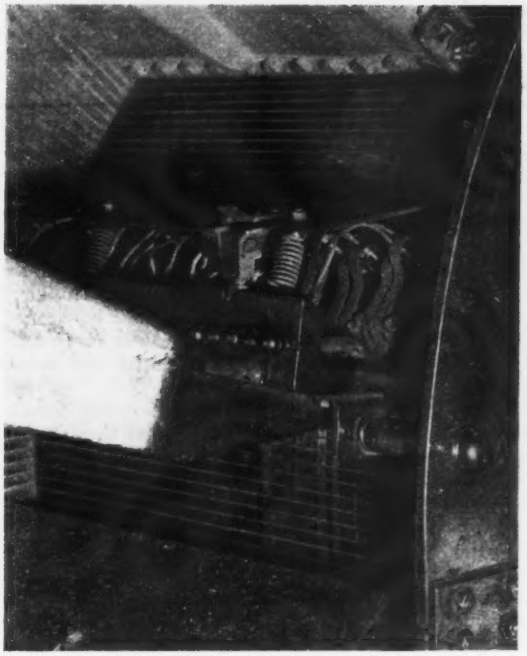


Fig. 6—Commutator grooving on 2500 kW. generator

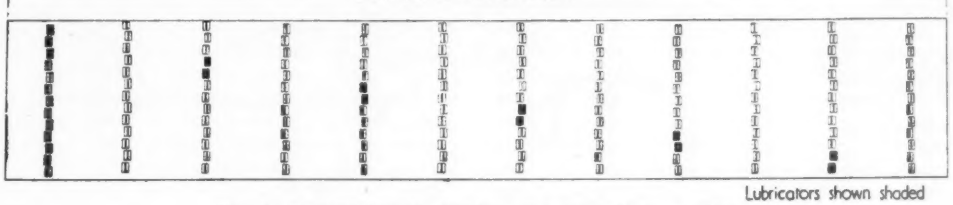


Fig. 5—Disposition of brushes on commutator surface

solved but, unfortunately, on the old machine after about 3000 hours' running, grooving began to develop at one or two points, and after about 7500 hr. the tracks were right across the commutator. The other machine ran for about 6000 hr. before showing signs of grooving, and after 8500 hours' running there are only two adjacent tracks, the rest of the commutator being in first-class condition, as shown in Fig. 6.

An effort is being made to check the trouble on this machine, and the older machine's commutator, which has again been diamond turned after only 8500 hours' running, is having very careful attention in an effort to prevent further recurrence of this trouble.

The same type of routine work should be carried but on alternators, except that the task is very much easier due to the absence of commutator and brush gear.

With regard to the use of rectifiers in steelworks, it would seem obvious and desirable that they should take the place of rotary equipment because they are very reliable, there is practically no maintenance, and attendants are not necessary.

Main Drives

Large electric drives are usually operated on the Ilgner system, and in such cases there is a station attendant, who handles normal maintenance. This is mainly a question of keeping the station spotlessly clean and of closely watching the generator, flywheel, motor bearings, and the commutator and brush gear. The bearings are pressure fed, and due attention must be given to the pumps which are usually changed every year. The oil for the bearings is also tested every 6 months by the oil manufacturing company and is changed when necessary. At the week-end the commutator and brush gear are closely examined, new brushes fitted and bedded in where necessary.

The solution and water level in the slip tanks have to be examined and brought up to the required level and strength during the week if necessary. The generators and motors are usually cleaned by pressure air once a fortnight.

On smaller drives it is quite usual to find an A.C. motor and flywheel type of equipment where an attendant is considered unnecessary. The motor is cleaned every week, the air gap checked every month, and at holiday periods the flywheel and motor bearings are carefully examined.

Transmission

It is unfortunate that there are such things in steelworks as overhead feeders radiating from a central power plant. Particularly with D.C. feeders, the large number of heavy copper cables and their supporting structure, which are exposed both to the elements and to corrosive fumes, ultimately necessitate a considerable amount of maintenance if trouble is to be avoided. In steel plants, where the work is of an almost continuous nature, it may only be possible to get the power off the lines for a few hours at the week-ends, and even then the overhead-line repairs have usually to be confined to a few week-ends during summer months, consequently the lines very often do not receive the attention they require and faults are encountered. To make matters even worse, from the maintenance and break-down repair stand-point, many of these lines run across tops of buildings with corrugated sheet-iron roofs which are often corroded and unsafe.

Where such feeder systems must be employed maintenance can be simplified and faults reduced by using overhead lines only where open ground has to be spanned.

Experience shows that these overhead cables can be so troublesome that it is necessary to embark on a scheme for dismantling as many as possible. Over long distances between shops, and between shops and power station, overhead lines may be retained, but elsewhere they should be cut down and replaced by armoured cables running in proper ducts. Excessive voltage drop, often encountered due to the inadequate carrying capacity of old overhead lines, is eliminated by the installation of well-designed cable runs.

Modern steelworks practice is to erect rectifier substations situated near the main producing units, thus very substantially simplifying the distribution system by discarding many heavy cables carrying direct current and substituting a single comparatively light cable carrying high-tension alternating current.

The use of properly designed insulators and insulator supports at terminal and intermediate cable towers also simplifies maintenance. For low- and medium-pressure D.C. systems, one type of terminal insulator arrangement which is quite common but not very satisfactory, particularly when used in melting shops and soaking pits, is as shown in Fig. 7. During wet weather sulphur dioxide in the gases from the furnaces combines with water to form sulphurous acid, and a good leakage path is provided from the conductor to the supporting steel work, hence electrolysis is set up and wasting of the positive conductor is usually fairly rapid. The placing of a steel bolt

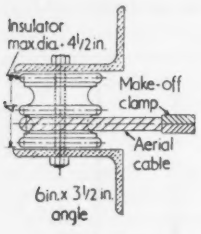


Fig. 7

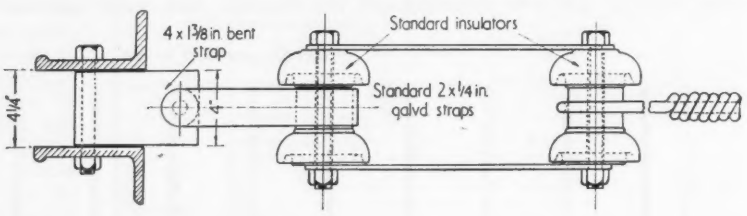


Fig. 8

Fig. 7—Overhead low-tension cable make-off detail
Fig. 8—Overhead low-tension cable make-off assembly

through the hole in the centre of the porcelain is also unsatisfactory, since growth of the bolt due to rusting tends to burst the insulators, and the whole arrangement lacks flexibility. A better method is shown in Fig. 8, where the insulators are provided with two sheds to increase the leakage path and a galvanized steel tube is cemented into the centre of the porcelain to prevent bursting due to bolt growth. This system is flexible, and the double insulator reduces the possibility of earth fault.

The use of vulcanized-indiarubber-covered cable supported on cleat insulators may be quite satisfactory inside certain buildings but should be avoided inside melting shops, since corrosion at the stalks of the insulators may develop. The use of armoured cable is a much more satisfactory proposition.

Switch Gear and Transformers

For both high-tension and low-tension switch gear used on normal duty, the maintenance is confined to thorough cleaning and examination of insulators, tripping mechanism, etc., at holiday periods. Depending on the duty, it is usual to examine the oil at given intervals and, in each case, a note is taken of the frequency of tripping, and the oil is examined after six trips and changed if necessary. Oil circuit breakers controlling electric furnaces are, however, a different proposition, being subjected to severe load fluctuation and frequent tripping, and are carefully examined weekly, the oil is changed when there is the slightest sign of deterioration and, in any case, every 6 months.

There is really very little maintenance to be done on transformers; this is confined to taking regular samples of oil twice a year from the top and bottom of the tank and having them analysed and pressure tested. These test results are recorded, and whilst acidity of the oil does not materially affect dielectric strength, it attacks windings and insulation, and for this reason it must not be allowed to become excessive. The presence of a small quantity of water does, however, reduce dielectric strength considerably, and when this is noticed the oil should be passed through a centrifuge which will remove excess water and reduce sludge.

The working temperature of a transformer should be noted from time to time, and if there is any appreciable rise above normal, which is not attributable to overload, it is advisable to remove the core and windings from the tank for examination and remove the sludge which will in most cases be responsible for the condition.

Auxiliaries

Generally, the system adopted is one of careful inspection at regular intervals with a proper inspection report, and a further report, at a later date, of work carried out based on the inspection report. It is usually impossible to do everything that should be done within a specified period, as the time available for inspection and routine maintenance on many auxiliaries is very limited in most steelworks, and in some cases may only amount to a few hours a week. Nevertheless, the idea of routine inspection and maintenance is fundamentally sound, and by judicious planning and concentration on important equipment much can be accomplished. If the plant is not running continuously some of the work can be done during the week, but more often than not the concentration of work on maintenance is at the week-end.

To give some indication of the kind of routine adopted, one electrician may, for example, have several circuits to attend to during his shift. He starts off with the motor, examines the oil level and makes sure that the oil rings, where these are fitted, are running. On ball-bearing motors it is only necessary to grease every 3–6 months, and to remove for examination and cleaning every 2 or 3 years. The electrician then cleans the commutator, goes over all the brush gear, and checks the insulation at the connections and where connections enter the motor carcass. If there is any sign of trouble which he cannot handle in his shift he reports to his foreman, who either sends assistance or takes the decision to change the motor. The electrician tends all the motors first thus leaving sufficient time to carry out any lengthy repair or a complete motor change should this be required. He then proceeds to the contactor panels and for servicing these he is provided with an oil-can and brush and has quick access to stocks of spare contactor tips, new flash boards, new terminal posts, coils, and complete assemblies. The front of the panel is brushed down, burned contactor tips are changed, connections are examined, and spindles are given a slight coating of oil. The back of the panel is then exposed, brushed down and examined for loose connections, deteriorating insulation, etc.

The next job is the master controller, which is cleaned and serviced in the same way, and finally the panel is switched into circuit, the contactor timing checked, and the ammeter reading taken. If there is anything unusual about this reading which cannot be traced to an electrical fault then the mechanical department is informed. The same sort of maintenance is carried out on drum controllers, starters, etc., throughout the works.

Motors

Direct-current motors, A.C. slip-ring motors, and A.C. commutator motors must receive regular attention if for no other reason than to ensure that the brushes are free in the boxes and that the bearings and air gaps are satisfactory.

The question of routine changing of motors for overhaul introduces a rather controversial point and, whilst some engineers feel that it is better to give the motor a routine check and leave it to run until it fails, others take the view that the life of a motor, for its particular duty, should be assessed, the motor replaced at definite intervals, and the old one taken back to the shop for dismantling, inspection, repair, and finally sent to the stores as a first-class spare.

There may be well over a thousand motors in one plant and to suggest routine changing of them all is very much like a counsel of perfection, and quite probably an uneconomic proposition. On the other hand, the suggestion that all motors which are running satisfactorily should be left alone, disregards the fact that there may be incipient faults in a very important motor which may be difficult to change,

and which, if it had a breakdown, would lead to considerable loss of output. It would appear that a compromise between the two views is the correct answer, and each motor in the works should be judged on its merit, important motors in difficult situations should be changed at intervals the length of which will depend on the nature of their respective duties. On one of the plants with which the writers are associated this scheme has been organized but has not been going long enough to prove its merit, although one good point which has emerged is that it is easier to plan motor repairs and rewinds through the repair shop, and it is felt that eventually it may be possible to confine this type of work to normal working hours during the week.

Control Gear

Contactor equipment must be ventilated, otherwise the repeated arcing at the contacts might lead to ionization and ultimate dielectric breakdown of the air trapped inside the sheet-metal housing. At the same time the many moving parts and small contacts must be kept reasonably clean and sufficiently lubricated if faulty operation or breakdown are to be avoided. It is essential to keep such control equipment clean, but the task of doing so is often difficult as, for example, on many melting shop overhead cranes where contactor equipment is exposed on top of a crane-auxiliary girder. Another factor that militates against good maintenance is the arrangement of equipment, particularly with regard to overhead cranes where, in many instances, even on some modern machines, it would appear that the control gear is placed on the machine as a mere afterthought. The provision of adequate and properly designed accommodation for such equipment would in many instances add but a small percentage to the cost of the machine, and the consequent easing of maintenance with its resulting benefits would undoubtedly justify the extra expenditure.

Wiring, Crane-Main Leads and Collectors

Routine megger testing of machine wiring is not recommended, since the trouble involved far outweighs any advantage to be gained. Periodical examination of exposed wiring and wiring terminations is well worth while, since as a rule it is at this point that most wiring troubles are experienced.

Crane-main leads such as **T**-bars or angles are very often forgotten until something goes wrong, and here again, occasional examination of insulators, joints, and bonds is recommended. The frequency of such examination need not be very great, and attention to any particular run every one or two years will probably be sufficient. The weekly application of a lubricant such as a graphite-and-tallow mixture is advisable, since it helps to reduce considerably the wear of the leads and collector pads.

To simplify maintenance it is also advisable to reduce the number of joints to the minimum, and this point might well be brought to the attention of designers and draughtsmen. Trolley-wire collectors, particularly if of the brass slipper or spindle and pulley type, require regular cleaning and lubrication, and failure to do this will certainly lead to trouble. Maintenance can be simplified and reduced by fitting collectors of the triangular carbon type used in conjunction with shunts and arranged as shown in Fig. 9. These will give very satisfactory service even on fairly heavy duty motions and particularly in cases where there is a tendency for the trolleys to jump off the collectors.

BREAKDOWNS

The first object of course is to eliminate or reduce to a minimum the incidence of breakdown and, as previously mentioned, it is endeavoured to do this by giving the plant the maximum amount of inspection and by organizing planned maintenance.

Having done everything practicable to anticipate failure, the next step must be the rapid handling of breakdowns. Spares must be intelligently distributed throughout the works, and in such a manner that whilst they are kept in good condition they are readily available. Handling facilities should be sited carefully and, in places not covered by a crane, block and tackle, slings, etc., should be kept in readiness. In addition it is desirable to have small stores available in various parts of the works for storing contactor tips, contactor assemblies, controller barrels, small quantities of cable, special tools, bolts and nuts, etc. Where possible, a spare motor should be kept near the main producing units, and in the melting shop there should be one spare of each type of motor used in this part of the plant. In areas where perhaps a high degree of standardization has been reached it is better to keep a spare motor where it can be lifted

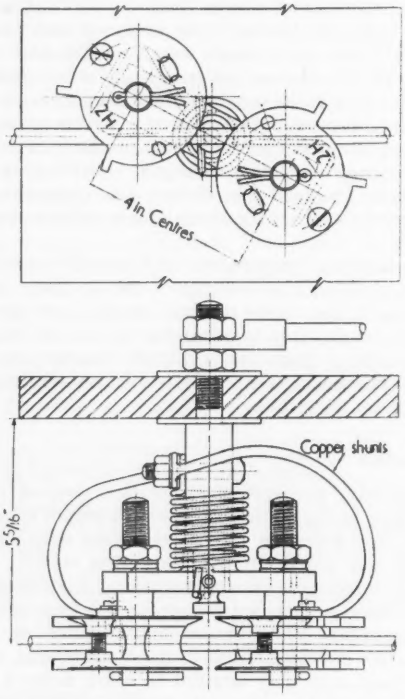


Fig. 9—Crane collector with carbon inserts

by a crane, and within reasonable distance of the working motors for which it is a spare.

The majority of breakdowns are minor, and except in the case of a complete motor failure or an awkward wiring fault they do not usually cause delays of more than a few minutes. These small delays are usually caused by a ruptured fuse, a sticking contactor, burnt-out contactor coils, and so on. All breakdowns, whether they involve stoppage of production or not, should be thoroughly investigated for the purpose of diagnosing the cause and finding ways and means, if possible, for preventing a recurrence. Such investigations may reveal a fault on some other part of the equipment which, apart from causing a recurrence of the fault which led to the investigation, might lead to a more serious breakdown later on. For example, on an important crane the main collectors came off the live steel **T**-bars and jammed between the latter bars and the gantry girder. The job was repaired, and on closer examination at a more convenient time it was discovered that the bracings on the crane-auxiliary girder, to which the collector gear was fixed, were fractured, thus allowing the girder to sag and causing the collectors to lie low.

It is advisable to have some method of recording breakdowns, possibly a simple form of card index on which is noted the nature and cause of the breakdown, whether a repair is temporary or permanent, the time the machine is idle, and the production delay. Failure to have such a system means that over a period there is no reliable guide as to machine performance, and usually leads to an accumulation of temporary repairs which in time will give a considerable amount of trouble.

Most electrical breakdowns can be classified as follows:

(*a*) Winding faults
(*b*) Breakages of armature shafts
(*c*) Control equipment faults
(*d*) Wiring faults, and
(*e*) Lifting-magnet and magnet cable faults

Winding Faults

Modern totally enclosed D.C. mill-type motors will stand up to very severe working conditions and give very little trouble. On very odd occasions armature-coil insulation may break down to earth at the corner of a core slot, but mica plate reinforcement at that point greatly reduces this possibility. This kind of fault is common to many types of armature, and it is thought advisable to make the fitting of mica plates at the corners of core slots standard practice. In one instance, in a breakdown of this nature, it was interesting to note that the corners of the slots had been reinforced with micanite instead of mica. This armature was part of an old-type mill motor and the design of the coils was such that when the end bands were put on there was a tendency for the coils to be pulled hard in against the core corners, hence there was the possibility, particularly since the working temperature of this machine is very high, that the micanite softened under heat and collapsed. However, since this armature was a complete rewind and had only been in service for a few days, it is difficult to believe that breakdown of the micanite could have been responsible, since, in addition to this, the slots were lined with leatheroid and the coils were wound with asbestos-covered wire and taped with varnished cambric and surgical tape, the armature also having been dipped in heat-resisting enamel and stoved. There is, of course, the possibility of faulty workmanship, and in this connection it may be worth while emphasizing the need for adequate testing equipment in the repair shop. It is suggested that all rewound jobs should, on completion, be meggered and then flash tested, although the latter test is not advisable on old machines which have been repaired, since there is always the possibility of premature breakdown due to overstressing of the insulation during the test.

Carbon dust which accumulates rapidly in totally enclosed machines eats into the insulation, and is sometimes responsible for the breakdown of armature and field windings. A considerable amount of steel dust also seems to find its way into this type of machine, mainly through the horizontal seam of the casing, which may be open one to five thousandths of an inch at parts, and through the connection holes in the side of the casing. Periodical use of a vacuum cleaner is a worth-while proposition for totally enclosed machines, and the complete exclusion of steel dust could possibly be arranged by paying particular attention to the horizontal seam and by sealing the holes for the connections.

Broken Armature Shafts

These are probably most often encountered on mill racks and cranes of old design where there is open-type gearing very often rigidly coupled to old mill-type motors with shafts having a very much lower factor of safety than the modern mill-type motor. Excessive wear of bearing brasses of extension shafts on many of these drives is a common cause of trouble. For example, it is not unusual on an old crane to find the arrangement of a motor fitted with a brake wheel and rigidly coupled to an extension shaft carrying the first-stage reduction pinion and supported at the tail end by a grease-lubricated bearing block. There is no intermediate bearing between the motor driving end bearing and the extension-shaft tail bearing, consequently it is not possible to fit a flexible coupling, and the result is that wear of the tail-end bearing brasses causes misalignment and leads to the setting up of alternating stresses which in time will cause the armature shaft to break.

It is advisable, where drives of this type are in use, to introduce if possible an intermediate bearing and a flexible coupling of the pin-and-rubber buffer type, which in our opinion is likely to give less trouble on this form of drive than the toothed coupling and continuous spring design. When such an alteration is not possible the extension shaft should be bolted to the armature shaft and aligned in the repair shop, and when an armature or motor requires changing it should be installed complete with its own extension shaft and new bearings. It has been found that some plant designers have fitted ball-bearing motors connected through solid couplings to shafts running in sleeve bearings. This causes a good deal of trouble;

such a specification should be avoided and extensive use made of flexible couplings. Fatigue cracks in armature shafts nearly always occur at the fillet, and if it is not possible to dispense with the fillet and substitute a taper it is very important that the former should be properly machined.

There can be no doubt that a very careful check on alignment will reduce breakdown considerably. Flexible and solid couplings should be carefully fitted and aligned and fitted bolts should be used with the latter. Pinion drives must be accurately lined up so that the meshing is correct, and care taken to see that the whole tooth face takes the load. A little time spent on this is not time wasted, but very much the reverse.

Control Equipment Faults

On contactor equipment troubles are mainly confined to details such as dry or worn pins, burned contacts, dirty or oxidized auxiliary contacts, broken flexibles, broken springs, and faulty operating coils. Apart from regular examination, cleaning, lubrication of pins and mechanical interlocks, and renewal of contacts and suspect flexibles, little can be done to prevent these troubles from occurring occasionally, although on any well-designed, properly installed, and well-maintained modern mill-type contactor unit such troubles are very infrequent.

On electric overhead cranes other control equipment faults such as broken slates, loose and broken connections, cracked drum-controller casings, and broken supports and grids of starting resistors, are very often the result of poor crane-rail maintenance or of collision between cranes in the same bay. The use of cast steel or fabricated drum-controller casings and unbreakable rustless grid type of resistances removes some of these problems, but others are not so easily solved except by adequate and regular attention to the crane rails and road wheels.

Wiring Faults

The amount of trouble likely to be experienced with wiring for cranes and other auxiliaries depends largely on the sensible choice of wiring materials and the lay-out of the installation. The degree of cleanliness in the vicinity of wiring runs and the quality of workmanship have also a large bearing on this matter.

Some of the factors which lead to breakdown of wiring for rolling-mill auxiliaries are as follows:

(1) Ingress of water from water and hydraulic pipes to V.I.R. and A.V.C. cable in conduit.
(2) Exposure of V.I.R. and A.V.C. cable to heat.
(3) Burning of V.I.R. or A.V.C. cable in conduit and armoured cables due to external oil or grease fires.
(4) Earth faults due to untidy wiring terminations at motors and controls, etc., where very often wires are left loose to foul metal structures, which themselves may be subject to vibration.
(5) Relative movement between parts of overhead crane structures causing broken conduit joints.
(6) Damage to conduit and cabling around roll housings.
(7) Breakdowns of cable in conduit due to vibration of machinery or to the force of attraction or repulsion set up between current-carrying conductors.

When planning and carrying out new wiring installations or alterations to existing wiring systems all these factors should be given consideration in an effort to ensure a satisfactory job. Consider, for example, the recurring trouble experienced with melting-shop cranes which are wired with V.I.R. in conduit. The V.I.R. perishes rapidly, and there are too many failures due to fracture of the conduit running between parts of the crane which can move relative to each other as between the main girders and control cabin. A better method is to use A.V.C. armoured cable, installing multi-core cable for the control and other circuits, and only resorting to the use of single cables where multi-core ones are going to be unduly clumsy. This method has proved successful, and no trouble has arisen since the first installation was completed three years ago.

Lifting-Magnet and Magnet Cable Faults

Most lifting magnet troubles are the result of the ingress of water or moisture-laden air which find their way into the magnet as the result of imperfect impregnation. The latest type of magnet has been filled with a mixture of a suitable baking varnish and silver sand which has been dried and cleansed of metal particles. This magnet has been in service for several months in a melting-shop marshalling bay and has been completely satisfactory. If and when trouble occurs there may be some difficulty in removing the hard sand and varnish mixture from the magnet, and it remains to be seen whether this method of filling is superior to that where a magnet has been properly pressure impregnated with bitumen compound as distinct from one where the compound is merely heated and run in.

Broken and shorted T.R.S. magnet cables on hard-worked scrap-handling overhead cranes provide the maintenance electrician with something of a problem. Many devices have been tried out, and so far as we know none has been entirely successful in eliminating trouble, although the arrangement shown in Fig. 10 has in some instances considerably reduced the incidence of long cable faults. Damage to the short sections of cable from the rope blocks to the magnet provides an even more difficult problem. Troubles with these are mainly caused by the cable catching on wagons or scrap falling on top of the cable and piercing it, and so far as is known no one has produced a satisfactory method of preventing such trouble. Reinforcement of the cable sheath by fitting a rubber hose pipe and bringing the cable from the terminal box in towards the centre of the magnet tends to reduce the chance of damage.

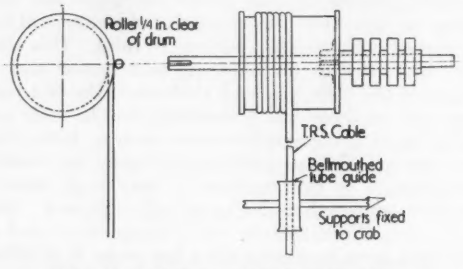


Fig. 10—Magnet cable take-up gear

It is impossible, within the scope of this paper, to detail all the faults and troubles which can occur in a steelworks, but the following are a few examples to illustrate to some degree how well it pays to go into detail, and also to give an example of the difficulties which can sometimes be overcome by a keen team of engineers.

A great deal of electrical trouble was experienced with old rack drives, and, due to excessive vibration, it was found very difficult to keep the motor tight on its seat. A special type of locknut was fitted to the motor foot bolts with results far exceeding expectations. Another serious trouble was the large number of rope breakages on skid gear. Great attention was paid to this equipment, the ropes being constantly tensioned and the whole gear kept in really good order, but without much reduction in the frequency of breakdown. It was decided finally to fit a fluid flywheel on the drive, and this has resulted in a reduction of over 50% in rope wear and cost.

On one plant there were many failures of very old motors on old drives with open-type gearing. Because of possible extensive alterations to the plant lay-out within a few years it was considered uneconomical to purchase new racks and skid gear, but it was decided to proceed with the fitting of modern-type mill motors. To enable the correct size to be determined the R.M.S. rating of the existing motor was found by shunting a percentage of the current through a resistance and measuring the heat loss over a period of time.

Improvisation of necessity plays a very large part in maintenance work, as the failure of any item of plant will quickly reflect on production, and methods must be devised for getting the faulty plant into operation as soon as possible. As an example, the case may be cited of a reversing cogging-mill drive where the 3800-h.p. driving motor of the flywheel set broke down. In this instance the motor, as well as driving the variable voltage generators feeding the cogging-mill motor, drove a 750-kW. 250-V. auxiliary D.C. generator. By converting this generator into a motor fed from the works supply, it was found possible to keep the cogging mill in operation with only slightly reduced output while the repair to the main driving motor was carried out.

An automatic voltage regulator in the field of the motor was used to produce the fall in speed necessary to allow the flywheel to equalize the peaks drawn from the mains, and collaboration between the motor house and the mill prevented excessive load demands being called for.

A major failure on a machine of this type is a very rare occurrence, and experience has shown that even after 25 years' service little deterioration has taken place in either armature or field windings.

Although there is a good deal of co-operation between designers and maintenance engineers, even closer collaboration is desirable, not so much from the design of individual machines but from the plant lay-out point of view. Designers have helped very greatly as in the case of gear boxes fitted with a double shaft extension with a motor on either side of the gear box, so that if one motor fails the minimum time is lost in restoring working conditions. There are too many cases, however, of motors and control gear placed in awkward positions, where little thought has been given to the ease of keeping gear clean, and, due to cramped conditions, engineers find difficulty in servicing or changing motors.

SAFETY MEASURES

The need for adequate safety precautions for electrical equipment is, for obvious reasons, probably more important than in many other spheres. Generally, in the case of low- and medium-pressure A.C. and D.C. work where most of the equipment is handled by non-engineering personnel, there is probably as much, if not more, need for almost fool-proof protection as there is with high-tension work which is dealt with mainly by skilled engineers.

On cranes, mill auxiliaries, portable tools, and portable handlamps, etc., adequate over-current protection is essential and this provides the works' electrician with one of his major problems. It is most difficult in large works to prevent interference with fuses by unskilled personnel, and in many instances, operators or other employees, rather than send for an electrician, repair ruptured fuses themselves, very often with wire which is much too heavy for the circuit to be protected. The result is, of course, that on the occurrence of a fault, particularly where portable tools or handlamps are concerned, the fault current reaches a high value and the operators receive burning injuries. There is a danger, in many cases, of live metal being fouled or of the fuse being closed when fault conditions still exist on the circuit and, strictly speaking, when a fuse ruptures, the electrician should carry out tests to ensure that the circuit is clear of fault conditions. Unfortunately, such a procedure would often lead to considerable delay on production units and, consequently, an operator, mill fitter, or crane driver, if he happens to be on the spot, replaces the fuse as quickly as possible. Where this must be done it is desirable to have correctly loaded spare fuses stored at the spot where they are required, and it is also essential that these fuses should be of such design that on closing the circuit, danger to the operator is reduced to a minimum. The problem does not exist to the same extent on modern distribution panels where switch and fuse units are in separate metal-clad chambers mechanically interlocked, although even with equipment like this there is still need for properly loaded spare fuses to be available on site.

For over-current protection of small units such as portable tools and handlamps, it is probably advisable to dispense with local fusing at each point and have all circuit fuses for a particular area in one fuse distribution unit which should be padlocked. In addition, when such equipment is connected to A.C. supply mains, the use of small step-down transformers is strongly recommended.

In view of the fact that a large number of electrical accidents occur with portable tools and handlamps, particularly on A.C. circuits, it is most important that the apparatus should either be all insulated or effectively earthed, and for this purpose it is essential that this equipment should be examined periodically,

particular attention being paid to the earth wire connections.

CRANE PROTECTION

Many electrical accidents occur on cranes, and while it is almost impossible to devise a completely foolproof system, many advantageous arrangements can be made.

First, there is the question of instructing the personnel, and it should be insisted that when an electrician is working on cranes he should first of all place a danger notice on the main switch. Unfortunately, the human element comes into the picture straight away, because even if such a notice is kept in each crane cabin a careless electrician may not use it. When the electrician is on the crane he may wish to study something while it is working, and he naturally has to depend on an apprentice or crane driver to close the main switch and carry out the required operation. Mistakes can occur here, and it is felt that one cannot go further than adequate safety-first instruction for the men concerned. It should be clearly understood, however, that when an electrician is on a crane he is definitely the man in charge.

One of the dangers with electric overhead travelling cranes is the entry of unauthorized persons to the walk-way on the main girders. Where practicable this walk-way should be on the side remote from the trolley wires, but even then it is quite easy to cross over to the other side. This difficulty may be overcome by placing the trolley wires in the bosom of the main girders, but this makes maintenance difficult and is unsatisfactory on machines such as magnet cranes, where swinging ropes can cause endless trouble. One method of overcoming this danger is to fit a switch on the trap door leading from the driver's cabin to the top of the crane so that opening this trap door automatically isolates all parts of the electrical gear.

SPARES AND STANDARDIZATION

The different types and numbers of spares to be carried must be decided by the engineer, based on his experience and knowledge of the plant. It is essential to have proper stores for small electrical spares, and this is usually operated on the bin system with some form of card index to indicate the week-to-week stock and give a clear indication of the time for re-ordering.

Larger electrical spares, like contactor panels, motors, etc., should also be kept under cover in a properly heated and ventilated building, and in connection with previous remarks made regarding the planned changing of motors, it is suggested that motors may be kept in better condition by putting them in commission and running them from time to time rather than by keeping them stored for excessively long periods.

These larger spares should also be entered in an index of some kind with full details of the working part of the plant for which they are spares. If this is not done confusion may result; for example, a motor may be spare for four other motors in various parts of the works, but if this spare motor is required it is vital to know immediately the degree of importance and history of the remaining three motors which are for the time being not covered by a spare. The consideration of these facts may determine whether the broken-down motor should be repaired during normal time or whether it is necessary to work round the clock until the spare is ready for service.

On smaller parts, investigation may show the possibility of standardization, and this is well worth looking into. To give one example, where solid couplings are used these are often of the spigot and faucet type, and the half-coupling fitted to the motor may be either male or female. Cases have been noted where a motor change was delayed due to the half coupling having to be removed and substituted for one to suit the half-coupling on the driven shaft. This may be overcome by agreement with the mechanical department to standardize the size of coupling for various shaft diameters and, instead of making two different half-couplings, to arrange to make two females with a ring between them. Couplings should be bored to jig, and by this means the above difficulties can be eliminated.

In this connection, collaboration between the engineers and draughtsmen or designers is important. These departments should be furnished with a list of existing types of pinions, brake wheels, etc., so that on a new design or extensive repair, new sizes are not introduced unless absolutely necessary.

Finally, the most important of all the aspects of satisfactory maintenance is the relationship existing between the departmental manager and his staff, and between members of the staff themselves. Too much attention cannot be paid to the close study of the personalities and idiosyncrasies of each individual in the maintenance department, and it is very noticeable that in a works where the men have faith in and respect for their foremen and managers, and where a high standard of law and order is maintained, an atmosphere of *esprit de corps* is created whereby the work of the department proceeds smoothly. Innovations are given a fair trial by the men, and the whole department works together as a team for the good of the Company.

The two foregoing papers together with the paper entitled "Electric Control Gear for Steel-Mill Auxiliaries" by R. A. West, which was published on pages 357–375 of the March issue of the *Journal*, will be presented for discussion at the Seventh Meeting of the Iron and Steel Engineers Group, to be held in London on Tuesday, 22nd June, 1948.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting

The Annual General Meeting of the Institute will be held on Wednesday and Thursday, 5th and 6th May, 1948, in the Lecture Hall of the Royal Institution of Chartered Surveyors, 12, Great George Street, London, S.W.1. The full programme of the Meeting will be found in the March, 1948, issue of the *Journal*.

Third Hatfield Memorial Lecture

The Third Hatfield Memorial Lecture will be given by Professor R. F. MEHL (Carnegie Institute of Technology, Pittsburgh, Pa., U.S.A.), on "*The Decomposition of Austenite by Nucleation and Growth Processes*," on Wednesday, 5th May, 1948, at 8.30 P.M., in the Lecture Hall of the Royal Institution of Chartered Surveyors, 12, Great George Street, London, S.W.1.

Protection of Steel against Atmospheric Corrosion and Marine Fouling

A Joint Meeting of The Iron and Steel Institute and the British Iron and Steel Research Association, to discuss several papers dealing with the protection of steel against atmospheric corrosion and marine fouling, will be held at 4, Grosvenor Gardens, London, S.W.1, on Thursday, 17th June, 1948. Mr. T. M. Herbert, Deputy Chairman of the Corrosion Committee and Chairman of the Protective Coatings Sub-Committee, will preside at the morning session (10.30 A.M. to 12.45 P.M.), and Professor J. E. Harris, Chairman of the Marine Corrosion Sub-Committee, at the afternoon session (2.15 P.M. to 4.30 P.M.).

The programme of the meeting is as follows:

Morning Session: 10.30 A.M. *to* 12.45 P.M.

"*First Report of the Methods of Testing (Corrosion) Sub-Committee*," to be presented by Dr. J. C. Hudson, Chairman of the Sub-Committee (published on p. 463 of this issue of the *Journal*).

Joint discussion on "*Service Trials of Painting Schemes Applied to a Steelworks Gantry*," by Dr. J. C. Hudson (to be published in the May, 1948, issue of the *Journal*), and "*The Protection of Iron and Steel by Various Non-Metallic Coatings*," by Dr. J. C. Hudson and Dr. T. A. Banfield (*Journal of The Iron and Steel Institute*, 1948, vol. 158, Jan., p. 99).

Afternoon Session: 2.15 P.M. *to* 4.30 P.M.

Joint discussion on "*Studies on Anti-Fouling Compositions*, by Dr. H. Barnes (*Journal of The Iron and Steel Institute*, 1947, vol. 157, Dec., p. 587), and "*Service Tests of Experimental Anti-Fouling Compositions*," by Dr. H. Barnes, Mr. M. W. H. Bishop, and Mr. K. A. Pyefinch (*Journal of The Iron and Steel Institute*, 1947, vol. 157, Nov., p. 429).

Joint discussion on "*Cementiferous Paints*," by Dr. J. E. O. Mayne and Dr. R. S. Thornhill (*Journal of The Iron and Steel Institute*, 1948, vol. 158, Feb., p. 219), and "*Marine Exposures of Cementiferous Painting Schemes*," by Mr. K. A. Pyefinch (*Journal of The Iron and Steel Institute*, 1948, vol. 158, Feb., p. 229).

A *Buffet Lunch* will be served in the Library of the Institute from 12.45 P.M. to 2.15 P.M. Members can obtain tickets (price 6*s*. each) for the lunch by sending a remittance to the Secretary of the Institute not later than Tuesday, 15th June, 1948 (envelopes to be marked "Corrosion Meeting Lunch").

Non-Members of the Institute are invited to attend the meeting and to join in the discussions. Separate reprints of the papers are obtainable for 2*s*. 6*d*. each and buffet lunch tickets for 6*s*. each, or a complete set of the seven papers and a buffet lunch ticket may be had for £1. Applications, accompanied by a remittance, should be sent to the Secretary of The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, to arrive not later than Monday, 14th June, 1948 (envelopes to be marked "Corrosion Meeting").

Awards

The Council of The Iron and Steel Institute has pleasure in announcing the following awards. Presentations will be made at the Annual General Meeting of the Institute on the first day, 5th May, 1948.

Williams Prize for 1947

The Williams Prize for 1947 (£100) has been awarded to Mr. R. FOWLER for his paper on "*Blowing-Out a Blast-Furnace*" (published in the April, 1947, issue of the *Journal*). Mr. Fowler received his early training in blast-furnace practice with Messrs. Bolckow Vaughan and Co., Ltd., and from 1921 to 1935 was engaged in blast-furnace work in India. On his return to this country he joined the firm of Messrs. H. A. Brassert and Company, later taking up a position with Messrs. Richard Thomas and Co., Ltd., where he is now blast-furnace superintendent.

Bessemer Gold Medal for 1948

In recognition of his contributions to the development of steel castings and to the production of alloy and heat-resisting steels, the Bessemer Gold Medal for 1948 has been awarded to Mr. W. J. DAWSON, C.B.E. Mr. Dawson joined the laboratory staff of Messrs. Hadfields, Ltd., after serving for three years in the laboratory of the works of Messrs. Henry Bessemer and Co., Ltd., and shortly afterwards was put in charge of the steelmaking department of their Hecla Works; he joined the Board of Directors in 1919. For nearly half a century he has been closely linked with all metallurgical developments of the firm.

Mr. Dawson became a Member of The Iron and Steel Institute in 1915 and was elected a Vice-President in 1946 and an Honorary Vice-President in 1947.

Sir Robert Hadfield Medal for 1948

The second award of the Sir Robert Hadfield Medal has been made to Mr. A. PREECE, Lecturer and Reader in Metallurgy at Leeds University, in recognition of his researches on the scaling and on the overheating and burning of steel. His previous positions include those of assistant metallurgist at the Pressed Steel Company of Great Britain, research assistant to Principal C. A. Edwards, F.R.S., at Swansea University, and research officer at the South Wales Siemens Steel Research Association. Mr. Preece is President of the Leeds Metallurgical Society, and an Honorary Member of Council of The Iron and Steel Institute.

Andrew Carnegie Medal

No award of the Andrew Carnegie Medal was made during 1947.

Selling Prices of Special Reports

As from 1st May, 1948, the prices of Special Reports of The Iron and Steel Institute will be as follows:

	Published Price	Rate to Members	Rate to Libraries and Technical Societies
Large reports ...	£1 5*s.* 0*d.*	15*s.* 0*d.*	£1 0*s.* 0*d.*
Medium reports	15*s.* 0*d.*	7*s.* 6*d.*	12*s.* 6*d.*
Small reports ...	7*s.* 6*d.*	3*s.* 9*d.*	6*s.* 3*d.*

Further details will be found in the revised price list on p. 49 of the advertisement section.

Reprints

Separate reprints of papers published in the *Journal of The Iron and Steel Institute* since 31st December, 1946, will no longer be on sale.

Seventy-Five Years Ago

The first paper at the Annual General Meeting of the Institute in 1873 was presented by Dr. (later Sir) William Siemens, F.R.S., on the manufacture of steel by a direct process. It was while he was endeavouring to perfect the process with which his name is identified with that of Martin, that is, the scrap process, that Siemens' attention was given to the production of steel from pig metal and ore, either in the raw or in a more or less reduced condition. First he produced spongy iron by one operation and consolidated or melted it by another. Having tried without success to effect this reduction in closed hoppers or retorts, he turned his attention to a rotatory furnace, which he erected at Landore in 1869.

This furnace consisted of a long cylindrical tube of iron, about 8 ft. in dia., mounted on anti-friction rollers; its brick lining was provided with longitudinal passages for heating currents of air and gas before their combustion at one end of the rotating chamber. The flame produced passed to the opposite or chimney end where a mixture of crushed ore and carbonaceous material was introduced. As the mixture slowly advanced to the hotter end of the chamber by the rotatory action it was gradually reduced to spongy iron which dropped on to the hearth of a steel-melting furnace where a bath of fluid pig metal was provided. The supply of reduced ore was continued until the carbon in the mixture was reduced to 0·1%. The rotation was then arrested to prevent further descent of reduced ore, spiegel was added, and the contents of the melting furnace tapped into a ladle from which ingots were poured.

Although the ore could be reduced in a comparatively short time, the furnace was immediately abandoned, as the spongy metal absorbed sulphur from the heating gases; also as the iron was not readily absorbed into the metallic bath, but floated on the surface, it was in part re-oxidized and converted into slag by the action of the flame in the furnace. Further experience proved, however, that by melting ores mixed with fluxing materials, the fused ore could be acted upon by solid carbonaceous matter to separate the metallic iron in a more compact form, the earthy constituents of the ore forming a fusible slag with the fluxing material.

By fusion of the iron obtained by this precipitation process on the open-hearth of a regenerative gas furnace, Dr. Siemens obtained steel of a very superior quality, specimens of which were exhibited at the meeting.

NEWS OF MEMBERS

▶ Mr. ALAN R. BAILEY has been appointed senior lecturer in metallurgy at the Constantine Technical College, Middlesbrough, to commence in April.

▶ Mr. HENRY C. BOYNTON has been appointed head of the new metallurgical department at Temple University.

▶ Mr. D. J. O. BRANDT has left John Miles and Partners (London) Ltd., and is now with the Steelmaking Division of the British Iron and Steel Research Association.

▶ Mr. S. C. BRITTON has left the Research Department of the L.M.S. Railway Company to take up an appointment with the Tin Research Institute, Greenford.

▶ Mr. H. R. CURNOCK has relinquished his position as chief metallurgist with the Wolsingham Steel Co., Ltd., and is now employed at "Wilson's" Forge (1929), Ltd., Bishop Auckland, Co. Durham, in a similar capacity.

▶ Dr. E. W. FELL has been appointed senior assistant in metallurgy at Bradford Technical College.

▶ Mr. V. C. HANSON has resigned the position of general manager of Kent Alloys, Ltd., Rochester, to take up an appointment as Director of Engineering Reconstruction Ltd., 18, Park Street, London, W.1. He has also been appointed a Director of Scottish Alloys, Ltd., North Hillington, Glasgow.

▶ Dr. W. D. JONES, consulting metallurgist, is undertaking an extensive tour of South Africa to study the development there of powder metallurgy.

▶ Mr. W. JUBB has left the Research Department of Samuel Fox and Co., Ltd., and is now metallurgist to British Jeffrey-Diamond, Ltd., Wakefield.

▶ Mr. R. D. KING has left the Scunthorpe works of Messrs. John Lysaght, Ltd., to take up an appointment as metallurgical chemist with the Straights Trading Co., Ltd. His address will be P.O. Box 700, Singapore.

▶ Mr. D. LANE is now with the metallurgical department of Messrs. Newton, Chambers and Co., Ltd.

▶ Dr. A. B. McINTOSH has left the Royal Technical College, Glasgow, to take charge of the Metallurgical Section at the Department of Atomic Energy, Risley, near Warrington, Lancs.

▶ Mr. C. MACQUARIE, formerly assistant Bessemer plant manager at the Corby Works of Messrs. Stewarts and Lloyds, Ltd., has been appointed chief metallurgist at the Company's Bilston Iron and Steel Works, near Wolverhampton.

▶ Mr. EDWARD T. MANN is now studying at the University of Adelaide, South Australia.

▶ Mr. BERNARD W. METHLEY has retired from the position of chief chemist of the Steel, Peech and Tozer branch of the United Steel Companies, Ltd. Mr. Methley, who was first associated with Steel, Peech and Tozer in 1901, will continue to serve in a consultative capacity at the Central Research and Development Department of the Companies.

▶ Dr. B. R. NIJHAWAN has been appointed Assistant Director of the National Metallurgical Laboratory, Council of Scientific and Industrial Research, Jamshedpur.

▶ Mr. B. PODCZASKI has resigned his post as assistant professor at the Polish University College, London, on being appointed metallurgical adviser to the Argentine Fabricacione Militares.

▶ Mr. S. L. ROBERTON, chief metallurgist of Clyde Alloy Steel Co., Ltd., is to be sales manager of the same firm.

▶ Mr. T. W. RUFFLE has resigned his position as metallurgist at the Kingston-on-Thames works of Leyland Motors, Ltd., to take up a post as metallurgist to the Motor Industry Research Association.

▶ Mr. GAVIN SMELLIE has been appointed works manager of the Steel Company of Wales, Ltd., Port Talbot, Glam.

▶ Mr. A. W. TAYLOR was on 1st November, 1947, appointed chief metallurgist to the Arc Manufacturing Co., Ltd., Actarc Works, London, W.12.

▶ Mr. W. S. TURPIN, previously metallurgical assistant to the chief chemist, British Railways, Western Region, is now metallurgist and technical manager with Messrs. Grey and Marten, Ltd., City Lead Works, Southwark Bridge, London, S.E.1.

▶ Mr. C. V. WILSON, having obtained the degree of B. Met., has left Sheffield University to join the Research Laboratories of Rolls Royce, Ltd., Derby.

▶ Mr. F. WALTON has taken up an appointment as manager of Alloy Steel (N.Z.), Ltd., Christchurch, New Zealand.

▶ Mr. D. H. WILLEY, previously with the Control Commission in Germany, has now taken up an appointment in London with the Ministry of Defence.

▶ Mr. P. WILLMOTT is now a metallurgical chemist at Messrs. Locke, Lancaster, and W. R. Johnson, Millwall Lead Works, 308, West Ferry Road, Millwall, London, E.14.

Elections

▶ Dr. S. F. DOREY, Chief Engineer Surveyor to Lloyd's Register of Shipping, distinguished for contributions to marine engineering, has been elected a Fellow of the Royal Society.

▶ Mr. THOMAS JOLLY (Guest Keen Baldwins Iron and Steel Co., Ltd.) has been elected a Member of Council of The Iron and Steel Institute.

▶ Dr. A. B. KINZEL has been elected President of the Union Carbide and Carbon Research Laboratories, Inc., New York.

▶ Mr. WILLIAM B. WALLIS, President of Pittsburgh (Pa.) Lectromelt Furnace Corporation, has been nominated as President of the American Foundrymen's Association, for 1948–49.

Memorandum

Messrs. Spencer-Bonecourt, Ltd., have now left their war-time office at Hitchin, Herts. Their new address is Audrey House, Houndsditch, London, E.C.3.

Obituary

The Council regret to record the deaths of:

Mr. JOHN D. GOLD, of Weirton Steel Company, Weirton, West Va., U.S.A.

Sir GEORGE A. MITCHELL, of 4, West Regent Street, Glasgow, on 16th February, 1948.

Mr. ROBERT BROWNE TENNENT, of Messrs. R. B. Tennent, Ltd., Coatbridge, aged 47.

CONTRIBUTORS TO THE JOURNAL

M. Y. Harvey, A.M.I.E.E.—Works electrical engineer at the Glengarnock Works of Colvilles, Ltd. After receiving his early education at Dalziel High School, Motherwell, Mr. Harvey studied electrical engineering, obtaining the Ordinary and Higher National Certificates in that subject. He served his electrical engineering apprenticeship with the Lanarkshire Steel Co., Ltd., Motherwell, and in 1938 transferred to the electrical department drawing office at the Dalzell Works of Messrs. Colvilles, Ltd. In 1942 he received further training with an electrical manufacturing firm and subsequently took up the position of assistant works electrical engineer at the Glengarnock Works. Mr. Harvey was appointed works electrical engineer in 1945.

G. S. Martin, A.M.I.Mech.E., A.M.I.E.E.—Chief engineer, Lanarkshire Steel Co., Ltd. Mr. Martin was awarded a diploma in electrical engineering at the Royal Technical College, Glasgow, in 1932. Having concluded his technical training he worked for short periods with Metropolitan-Vickers, Ltd., Manchester, and the Glasgow Corporation Transport Department, and joined the Clyde Valley Electrical Power Company in 1934. From 1937 to 1942 he was employed with Messrs. Brown and Aitken, London, where he was engaged in sales and consulting work. In 1942 he became an assistant to the chief electrical engineer at Messrs. Colvilles, Ltd., and was appointed works engineer at their Dalzell Steel Works in 1946. He took up his present position in 1947.

D. Marles—Chief metallographer at the British Cast Iron Research Association. Mr. Marles was educated at King Edward VI Grammar School, Birmingham, and at the Birmingham Central Technical College. He is an Associate Member of the Institute of British Foundry-

M. Y. Harvey

G. S. Martin

men, and a Member of the Royal Photographic Society. Mr. Marles joined the staff of the Association in 1940 and was appointed to his present position in 1944.

W. G. Thompson, Ph.D., B.Sc.(Hons.), M.I.E.E.—Assistant manager of the G.E.C. Rectifier Works, Witton, Birmingham. Dr. Thompson received his engineering training as a pupil at Sir W. G. Armstrong-Whitworth's Elswick Works, Newcastle-on-Tyne, and later at King's College, Durham University, where in 1928 he was awarded the J. G. Smith Prize and the degree of B.Sc. in electrical engineering with first-class honours. After a further period in the works he returned to the University to carry out post-graduate research in H.V. measurement for which he received the degree of Ph.D. and was awarded the Ferranti Travelling Scholarship of the Institution of Electrical Engineers. With this scholarship he spent two years in Germany at the Technische Hochschule in Munich and the T.H. Brunswick, carrying out research in H.V. rectification. In 1933 he joined the Research Staff of the G.E.C. Research Laboratories, Wembley, and four years later was appointed to his present position at Witton. Dr. Thompson is Chairman-Elect of the South Midland Centre of the Institution of Electrical Engineers.

IRON AND STEEL ENGINEERS GROUP

Seventh Meeting

The Seventh Meeting of the Iron and Steel Engineers Group will be held at the offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Tuesday, 22nd June, 1948, commencing at 10.30 A.M. Three papers are to be presented and discussed: "*Electric Control Gear for Steel-Mill Auxiliaries*," by R. A. West (published in the March, 1948, issue of the *Journal*), and "*Electronic and Servo Electronic Controls and their Application to the Iron and Steel Industry*," by W. G. Thompson, and "*The Maintenance of Electrical Machinery in Iron and Steel Works*," by G. S. Martin and M. Y. Harvey (published in this issue of the *Journal*).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

X-Ray Methods Sub-Committee

The New Techniques Committee of the Metallurgy Division has formed a sub-committee which will be concerned with X-ray methods. It is to be called the X-Ray Methods Sub-Committee and will be under the chairmanship of Dr. W. H. Taylor.

Ironmaking Refresher Course

A refresher course on "*Sintering, Distribution, and Blast-Furnace Reactions*," is to be held in 1948 at the Royal Technical College, Glasgow. Professor Hay is undertaking to arrange the course, the provisional dates for which are 28th June to 2nd July, 1948.

Staff

Mr. E. L. DIAMOND was on 20th February, 1948, presented with the George Stephenson Research Prize for 1947 by the President of the Institution of Mechanical Engineers. The prize was awarded to Mr. Diamond for his paper on "*The Development of Locomotive Power at Speed*," which was read before the Institution in February of last year.

Mr. R. HILL joined the staff of the Association on 1st March, 1948. He was previously at the Armament Research Department where he was engaged in research on plastic flow. Mr. Hill will be stationed at the Cavendish Laboratory, Cambridge.

NEWS OF SCIENCE AND INDUSTRY

The Flow of Ice and Other Solids

As announced in the March, 1948, issue of the *Journal*, a joint meeting between the Institute of Metals, the British Glaciological Society, and the British Rheologists Club is to be held at 4, Grosvenor Gardens, London, S.W.1, on Thursday, 29th April, 1948, at 3.45 P.M. The subject to be discussed is "*The Flow of Ice and Other Solids*," and Members of the Institute who may be interested are cordially invited to attend.

The meeting will include an exhibition of lantern slides and a film by Mr. Gerald Seligman, showing the methods of glacier research in the field, as used by the Jungfraujoch Glaciological Research Party in 1938. A discussion on the subject will be introduced by Dr. E. Orowan, F.R.S., and Dr. M. F. Perutz.

Physical Chemistry of Process Metallurgy

A General Discussion on the Physical Chemistry of Process Metallurgy, organized by the Faraday Society, will be held at Ashorne Hill, near Leamington Spa, Warwickshire, on Thursday afternoon, Friday, and Saturday morning, 23rd–25th September, 1948. The discussion will be divided into the following three sections: (1) Metallic solutions, (2) roasting and reduction processes, and (3) slags and refining processes.

Those who so desire will be able to remain until 27th September, 1948, for further informal discussions and visits to local places of interest, including the Shakespeare Memorial Theatre, Stratford-on-Avon.

A full programme of the meeting, together with details regarding accommodation and application for advance proofs of the papers to be discussed, will be announced in due course.

Seventh International Congress of Applied Mechanics

The Seventh International Congress of Applied Mechanics will be held at the Imperial College of Science and Technology, South Kensington, London, on 5th–11th September, 1948. Application forms for membership and other material concerning the Congress can be obtained from the Organizing Secretary at the above address.

Swedish Ores for the Combined Zones of Germany

An agreement has recently been signed in Stockholm for the import to the combined United Kingdom and United States Zones of Germany of 1,250,000 tons of Swedish ores. Delivery is to be at the rate of 50,000 tons during each of the months February, March, and April, and the total quantity is to be delivered by the end of this year.

Capper Pass Awards

The Directors of Messrs. Capper, Pass and Son, Ltd., Bristol, have offered to the Institution of Mining and Metallurgy and to the Institute of Metals the sum of £200 per annum for a period of 7 years, to be applied as follows:

(*a*) £100 per annum to be available for one or more awards to the authors of papers on some aspect of non-ferrous extraction metallurgy.

(*b*) £100 per annum to be available for one or more awards to the authors of papers relating to some process or plant used in the extraction or fabrication of non-ferrous metals.

Persons contributing papers are to be engaged full-time in industry or practice.

Institute of Metals (Platinum) Medal, 1948

The Institute of Metals (Platinum) Medal for 1948 has been awarded to Mr. Robert Crooks Stanley, Chairman and President of the International Nickel Company of Canada, Ltd., in recognition of his outstanding services to the non-ferrous metal industries.

MEMOIRS

Benjamin Talbot died on 16th December, 1947. Born on 19th September, 1864, at Wellington, Shropshire, he came of a family of long associations with the iron industry in Shropshire and the Black Country. At the works owned by his father the iron work for the Ironbridge over the River Severn—probably the first bridge to be constructed entirely of iron—was produced.

After being educated at the Moravian School, Fulneck, near Leeds, Mr. Talbot was for a time associated with his father in the running of the Castle Iron Works at Wellington, but in his early twenties began his career in the steel trade—then in its infancy—at the Ebbw Vale Works. Together with others whose names are well known in the steel industry throughout the world, Mr. Talbot devoted his time to the study of the open-hearth basic process, of which he was destined to become one of the leading figures. He went to the United States in 1890 to become Superintendent of the Southern Iron and Steel Company of Chattanooga, Tennessee, where he inaugurated the basic open-hearth process and was thus the actual pioneer in the production of open-hearth steel by the basic process south of the Mason-Dixon line. He carried out a great deal of experimental and development work at the Tennessee plant, which was operating on a high-silicon pig-iron. This led him to develop a preliminary refining operation designed to reduce the silicon content, and that item of plant has now become well known as the basic-lined gas-heated mixer.

In 1893 he became Steelworks Superintendent at the Pencoyd Steelworks, Pennsylvania, where he commenced the manufacture of basic open-hearth steel. Six years later he began the continuous steelmaking process which now bears his name, and in 1900 he presented his first paper to The Iron and Steel Institute on that subject.

Owing to a breakdown in health Mr. Talbot returned to this country in 1900; had this not been necessary he would probably have continued his career in the United States where the steel industry was rapidly expanding.

Shortly after his return Mr. Talbot became connected with Sir Christopher Furness, later Lord Furness, who died in 1912, in the recently re-formed Cargo Fleet Iron Co., Ltd., and in 1907 he was appointed Managing Director and successfully steered the company through its early years. In 1919 Mr. Talbot was appointed Managing Director also of the South Durham Steel and Iron Co., Ltd., and in 1925 Deputy Chairman of both companies. In 1940, on the death of Viscount Furness, Mr. Talbot was elected to the chairmanship of the South Durham and Cargo Fleet Companies, retaining the position of Managing Director.

Early in the 1914–18 war Mr. Talbot became a member of the small committee formed by the Government to advise them on the increased production of steel, and particularly of shell steel for our own use and that of our allies. The advice tendered by this Committee assisted in the ultimate formation of the Ministry of Munitions, and Mr. Talbot continued to advise this department in an expert capacity until the end of hostilities. He was also a member of the Board of Trade Departmental Committee set up immediately after the war to consider the position of the iron and steel trades, and was a member of the Coal Conservation Commission. In 1919 he was called upon as one of the industry's witnesses to give evidence before the Sankey Committee.

Mr. Talbot played a leading rôle in the formation of the National Federation of Iron and Steel Manufacturers, the forerunner of the British Iron and Steel Federation, and was its President in 1928, which coincided with his year of office as President of The Iron and Steel Institute. At that time the industry was slowly recovering from the disastrous effects of the 1926 coal strike, and Mr. Talbot urged the Government to introduce measures to safeguard the industry.

Mr. Talbot took an active part in the direction of business affairs until the end, and had been at work four days before his death.

In recognition of his inventions and researches in steelmaking, Mr. Talbot was awarded, in 1908, the Bessemer Gold Medal of The Iron and Steel Institute, and the Elliott Gresson Gold Medal and the John Scott Medal of the Franklin Institute.

J. S. G. Primrose died at his home at Acock's Green, Birmingham, on 2nd October, 1947, after a twelve-month's illness. Born in 1879, he received his early training at Allen Glen's School, Glasgow, and his business training at the Nobel Explosives Company, Glasgow. He became a student at the Royal Technical College and at the University, Glasgow, and in due course gained the A.R.T.C. diploma. He then spent nine years on the staff of the Royal Technical College; from 1905 to 1909 he was assistant to Professor Sexton in the Metallurgy Department, and from 1909 to 1913 was Lecturer in Metallurgy. During the summer of 1907 he carried out some research in metallography at Freiberg Academy in Saxony.

In 1913 Mr. Primrose left the teaching profession to become an industrial metallurgist; he went to the consolidated Diesel Engine Manufacturing Company at Ipswich, where he stayed for two years. From 1915 to 1922 he was with Ransomes and Rapier, also of Ipswich, and from 1922 to 1926 with R. Johnson and Nephew, of Manchester; in 1927 he joined the Whitecross (Wire) Co., Warrington, where he remained until 1935. In that year he went to the Rover Co., Ltd., at Tyseley, of which he was chief metallurgist at the time of his death.

Mr. Primrose was the author of numerous papers published in various technical journals. Although he contributed no paper to the Institute he joined on occasion in the discussion on communications by other authors. He was also author or part author of several textbooks, of which probably the best known is "*An Outline of the Metallurgy of Iron and Steel*," in which he collaborated with A. H. Sexton.

He was an active member of many technical societies; he was a Companion of the Institution of Mechanical Engineers, an Associate of the Institution of Mining and Metallurgy, and a Member of the Institute of Metals. He had been a staunch supporter of The Iron and Steel Institute for practically 40 years, for his election to membership took place in 1908.

Lt.-Col. **Arthur Hibbert** died on 19th December, 1947. A native of Manchester, he went to Canada at an early stage of his career to gain practical experience of mining engineering. He graduated at the Royal

School of Mines in 1910 and on the outbreak of war in 1914 he joined the Royal Artillery, later transferring to the Royal Engineers and then to the Canadian Army. After the war he travelled throughout the world as a mining and consulting engineer. In 1924 he joined the Millom and Askam Iron Company at Egremont as general mines manager, later becoming general manager and consulting engineer to the Alquife Mining and Railway Co., Ltd.; seven years later he was appointed general manager of the parent company and its subsidiary concerns. Colonel Hibbert took over this position in very difficult times, but by his energy, initiative, and ability he accomplished much and played a large part in modernizing the Millom plant.

About twelve years ago Colonel Hibbert became Chairman of the Cumberland Development Company and helped to bring new light industries to the county, then a distressed area. He was also a Member of Council of the British Iron and Steel Federation, and served on the Government's Advisory Committee on Metalliferous Mining.

Despite his busy career he was keenly interested in local life. From 1937 to 1946 he was a member of the Cumberland County Council, and served on the Millom Rural District Council. He was also a local magistrate.

Colonel Hibbert joined The Iron and Steel Institute in 1933.

DIARY

29th April

STAFFORDSHIRE IRON AND STEEL INSTITUTE—"*Scrap, from the Recoverer's Point of View*," by F. L. Levy—Victoria Hotel, Wolverhampton, 7.0 P.M.

3rd—7th May

AMERICAN FOUNDRYMEN'S ASSOCIATION—1948 Convention and Exhibition, Philadelphia, U.S.A.

4th May

CHEMICAL ENGINEERING GROUP OF THE SOCIETY OF CHEMICAL INDUSTRY—"*Recent Developments in Cast Iron*," by J. G. Pearce—Geological Society, Burlington House, London, W.1, 5.30 P.M.

6th May

LEEDS METALLURGICAL SOCIETY—Annual General Meeting and papers by student members: "*Electronics*," by F. Lindars, and "*Is our Iron and Steel Industry Efficient*," by R. D. Carter—Chemistry Department, Leeds University, 7.0 P.M.

28th May

SWANSEA AND DISTRICT METALLURGICAL SOCIETY—Annual General Meeting—Royal Institution of South Wales, 6.30 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the March, 1948, issue of the *Journal*, page 390.)

TRANSLATIONS AVAILABLE

No. 341 (German). W. LENNINGS: "Smelting of Basic-Bessemer Pig Iron from Low-Grade German Ores in the Blast Furnace with Acid Slag Practice." (*Stahl und Eisen*, 1938, vol. 58, Jan. 13, pp. 25–35; Jan. 20, pp. 52–58).

No. 342 (German). H. BABLIK and F. GÖTZL: "Alloy Additions to Hot-Galvanizing Baths." (*Korrosion und Metallschutz*, 1941, vol. 17, Apr., pp. 128–130).

TRANSLATIONS IN COURSE OF PREPARATION

(German). "The Possibilities of Influencing the Oxidation Zone of the Blast-Furnace." (*Stahl und Eisen*, 1947, vol. 66–67, Aug. 14, pp. 277–284).

(German). W. BADING: "The Development of Basic Converter Practice." (*Stahl und Eisen*, 1947, vol. 66–67, Apr. 24, pp. 137–149; May 22, pp. 180–186; June 19, pp. 212–223).

(Swedish). E. BERNHULT: "The Calculation of Roll Pressure and Power in the Cold-Straightening of Bars and Tubes." (*Jernkontorets Annaler*, 1944, vol. 128, No. 4, pp. 137–160).

(German). F. BLEILÖB: "Equations for the Time-Elongation Curves in Creep Tests." (*Archiv für das Eisenhüttenwesen*, 1940, vol. 13, May, pp. 489–496).

(German). A. EICHINGER: "Mathematical Treatment of Creep Curves." (*Archiv für das Eisenhüttenwesen*, 1940, vol. 13, Mar., pp. 397–402).

(German). Discussion of E. Houdremont and G. Bandel's paper: "The Effect of Titanium on the Creep Strength of Steels." (*Archiv für das Eisenhüttenwesen*, 1942, vol. 16, Sept., pp. 97–100).

(Swedish). W. KARLSSON: "The Possibilities of Using Liquid Fuels in Iron and Steel Works." (*Värmlandska Bergsmannaföreningens Annaler*, 1946, pp. 47–94).

(German). F. LÜTH: "The Moisture in Industrial Gases. Part II—Application of the Moisture Calculation." (*Archiv für das Eisenhüttenwesen*, 1930, vol. 4, Oct., pp. 185–192).

(Swedish). G. MALMBERG: "The Effect of Specimen Shape on the Elongation in Tensile Testing." (*Jernkontorets Annaler*, 1944, vol. 128, No. 6, pp. 197–245).

(Swedish). S. MÖRTSELL: "Rationalization in Swedish Iron Ore Dressing." (*Jernkontorets Annaler*, 1946, vol. 130, No. 9, pp. 369–460).

(German). W. OELSEN and H. WIEMER: "Immiscibility Phenomena in Ferrous-Oxide/Sodium-Phosphate Slags." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 13, pp. 167–210).

(German). A. POMP and W. PUZICHA: "The Cold-Rolling of High-Tensile Strip Steels and Their Properties." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1943, vol. 26, No. 2, pp. 13–36).

(Dutch). M. G. VAN DER STEEG: "The Heat-Treatment of Chains." (*Metalen*, 1947, vol. 1, June, pp. 190–192; July, pp. 207–209).

CHARGES FOR COPIES OF TRANSLATIONS.—For the above translations a charge will be made of 10*s*. for the first copy and 5*s*. each for each additional copy of the same translation. Requests should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

	PAGE
Fuel—Preparation, Properties, and Uses	527
Blast-Furnace Practice and Production of Pig Iron	528
Treatment and Use of Slag	528
Production of Steel	529
Production of Ferro-Alloys	529
Foundry Practice	530
Heating Furnaces and Soaking Pits	530
Heat-Treatment and Heat-Treatment Furnaces	530
Forging, Stamping, Drawing, and Pressing	533
Welding and Flame-Cutting	533
Powder Metallurgy	534
Properties and Tests	534
Corrosion	540
Analysis	541
Book Notices	543
New Publications	544

FUEL—PREPARATION, PROPERTIES, AND USES

Fuel Efficiency. A. C. Dunningham. (Manchester Association of Engineers, Feb., 1948, Advance Copy). The efficiency of combustion appliances and that of distribution and utilization of secondary media such as steam and power derived from the combustion of coal are considered. A final section deals with the general efficiency of plant and processes in which heat or power is used.—R. A. R.

Preheating of Fuels. Fuel Economy, Losses and Their Interdependence. J. Szczeniowski. (Chaleur et Industrie, 1947, vol. 28, Sept., pp. 231–238). In the first part the author studies the effect of various factors on fuel consumption, using an insulated preheating chamber where the only source of loss of heat was by the chimney. Results showed clearly that consumption of fuel in a furnace decreased with increased preheating. The second part deals with various sources of heat loss, and finally some practical applications of preheating are mentioned.—J. C. R.

Coal—A Vital Factor in Steelmaking. (Office Technique pour l'Utilisation de l'Acier). This pamphlet discusses the importance to the French steel industry of an adequate coal supply. Some notes are given on the pre-war and present-day position of the industry.—J. C. R.

The Application of Instruments and Automatic Control to Pulverized-Fuel-Fired Plants. J. E. O'Breen, S. J. Clifton, D. C. N. Gemmell, and Ll. Young. (Institute of Fuel, Mar. 3, 1948, Advance Copy). Attention is drawn to the need for instruments and control equipment for pulverized-fuel-fired boilers for electricity generating stations, and the problems underlying the satisfactory application of such apparatus are described and discussed.—R. A. R.

High Stability Gas Burners. L. T. Minchin. (Coke and Gas, 1948, vol. 10, Jan., pp. 21–24, 33). Although most gas burners have been quite robust the modern trend is towards even more stable types, and one phase of this development has been the increased use of non-aerated, or "neat gas" flames, which can neither light back nor be turned down to an extreme degree without loss of stability. Domestic and industrial burners utilizing this principle are described, and are of particular value where it is desired to employ thermostatic control. These developments have influenced the design of the aerated, or bunsen-type, burners, and examples are given of the extent and applications of such modifications.—J. R.

The Influence of Mechanisation on Coal Preparation. H. G. Hague. (Institute of Fuel, Feb., 1948, Advance Copy). It is shown that degradation of coal before its treatment in the preparation plant should be reduced to an absolute minimum even if the coal has eventually to be reduced to smaller sizes for coking after cleaning. A two-process method of coal cleaning is described. It has the following advantages: (*a*) Less degradation during the actual cleaning; (*b*) a higher yield of marketable products at specified ash contents; (*c*) a lower moisture content in the smaller sizes; (*d*) a lower power consumption per ton of raw coal input; (*e*) ability to deal with fluctuating loads and varying amounts of discard without resorting to raw-coal storage before cleaning.—R. A. R.

Fuel Economy in the Coal Carbonisation Industries. T. C. Finlayson. (Chaleur et Industrie, 1948, vol. 29, Feb., pp. 35–41). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 630.

A New Technique in the Construction of Coke Ovens. D. Petit. (Chaleur et Industrie, 1947, vol. 28, Mar., pp. 68–76). After reviewing the merits and drawbacks of coke ovens lined entirely with silica bricks, the author describes a "free expansion" coke oven having the lower part of the wall of silico-alumina bricks and the top part of silica bricks. As the latter expand more than the former, vertical spaces are left between the top bricks. Operational results with ovens of this type at Vendin in France are discussed.—J. C. R.

Shutting Down of a Battery of Coke Ovens at Morgantown. H. Bernet. (Chaleur et Industrie, 1947, vol. 28, June, pp. 162–164). This is a critical summary of an article by P. B. McCay which appeared in Blast Furnace and Steel Plant, 1946, vol. 34, Nov., pp. 1396–

1403. (*See* Journ. I. and S.I., 1947, vol. 156, May, p. 129)—J. C. R.

A New Process for the Recovery of Ethylene from Coke Oven Gas. P. M. Schuftan. (Physical Society : Chemistry and Industry, 1948, Feb. 14, pp. 99–104). A description is given of the large experimental plant at Corby which, by a new process, produces ethylene of 97% or more, directly from coke-oven gas, and as the main product. In this process the coke-oven gas used as a raw material requires purification only from tar, ammonia, naphthalene, and possibly benzole. The gas as taken into the plant thus contains the usual amounts of H_2S, HCN, moisture and CO_2.

The gas is first compressed to a moderate pressure and then precooled in a regenerator. Thereby water vapour, HCN, and hydrocarbons with more than two carbon atoms are completely removed by condensation, while about 97% of the H_2S and CO_2, about 40% of the ethane and 20–25% of the ethylene are also retained in the regenerators. After this efficient purification of the gas it is further cooled in an "equalizer," and in tubular heat exchangers, and a liquid crude ethylene fraction is separated. The gas, which is now practically free from ethylene, is then expanded in a turbine and this supplies about two-thirds of the cold requirements of the process. The expanded gas is rewarmed in tubular heat exchangers and in the regenerator and returned to the coke ovens. On passing through the regenerators it revaporizes completely the condensates deposited on the packing by the raw gas.—R. A. R.

The Application of Fuel Oil and Surplus Gas at an Integrated Iron and Steel Works. J. S. Kerr. (Institute of Fuel, Feb., 1948, Advance Copy). A description is given of the utilization of surplus gases in an integrated iron and steel works. Stress is laid on the value of instrumentation and automatic control for obtaining consistent operating conditions and lowest heat consumptions. The use of fuel oil in place of producer gas for the firing of open-hearth furnaces is described in detail. An account is given of the instrumentation required for an oil-fired furnace. Experiences gathered in the application of fuel oil to these furnaces are described. A comparison is made between the results obtained with oil firing on the ordinary 50-ton basic open-hearth furnace and on an all-basic furnace of the same size fired by producer gas. Some future trends in fuel-oil combustion technique are mentioned, particularly with regard to problems of atomization.—R. A. R.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Charcoal Blast-Furnace. W. H. A. van Alphen de Veer. (Metalen, 1948, vol. 2, Feb., pp. 117–120). [In Dutch]. A detailed description is given of a Swedish charcoal blast-furnace and of the blast preheater.—R. A. R.

Thermal Efficiency of Cowper Stoves. J. Szczeniowski. (Métallurgie, 1947, vol. 79, Dec., p. 17).—J. C. R.

Experimental Smelting and Refining of Iron–Chromium–Nickel Ore in Japan. R. T. C. Rasmussen and T. Kasahara. (General Headquarters, Supreme Commander for the Allied Powers (Tokyo), Natural Resources Section, Preliminary Study No. 12 : Chemical Abstracts, 1948, vol. 42, Jan. 10, p. 498). Experiments were made with the object of producing pig iron for plain carbon steel from Surigao, (Philippines) ore (analysis : Cr 2%, Ni 0·4%, Al_2O_3 15%, Si 2%). The ore had to be sintered by mixing it with pyrites cinder in the ratio 79/21. Surigao sinter can be smelted alone, but additional limestone must be used to offset the high Al_2O_3. Low-temperature acid smelting proved impractical as a means of removing chromium from the pig iron. Fairly normal blast-furnace operation was obtained by mixing 28% Surigao ore with chromium-free iron ore, and the pig iron thus produced had 0·87% of chromium and 0·20% of nickel. The basic converter effectively removed chromium, but not nickel, from this iron. The chromium can also be reduced to less than 0·1% in the open-hearth, provided that chromium-bearing slags can be removed from the furnace during refining. The quality of the steel thus produced is little affected by the chromium content.

Rapid Relining of Blast Furnaces. (Iron and Coal Trades Review, 1948, vol. 156, Jan. 23, pp. 157–160). An account is given of the methods by which a large blast-furnace was relined and restored to production in 43 days after blowing-out.—R. A. R.

Direct Consumption of Small Crushed Ore in a Blast Furnace. Gérin. (Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1947, vol. 4, Mar. 25, No. 5, pp. 51–60). A report is presented of an investigation into the circumstances in which small crushed ores can be used in a blast-furnace. Difficulties that arise and means of overcoming them are discussed, and a review is given of methods adopted in various countries.—J. C. R.

Investigation of Blast Furnace Downcomer Failures. C. M. Squarcy. (Blast Furnace and Coke Association of the Chicago District and Eastern States Blast Furnace and Coke Oven Association : Steel, 1947, vol. 121, Nov. 24, pp. 110–116). **Study of Blast Furnace Downcomer Failures.** C. M. Squarcy. (Blast Furnace and Steel Plant, 1947, vol. 35, Nov., pp. 1353–1356, 1377). The cause of failure of blast-furnace downcomers at the elbows was found to be erosion by the entrained dust. Improvements in life can be obtained by increasing the radius of the elbow, enlarging the diameter of the downcomer, lowering the gas velocity, and fitting a steel lining. In the Chicago district 28 ft./sec. has been found to be the ideal gas velocity. Data on hearth diameters, downcomer sizes, and gas velocities and pressures at several furnaces are presented.—R. A. R.

TREATMENT AND USE OF SLAG

Blast-Furnace Slag for Reconstruction. F. Keil (Stahl und Eisen, 1947, vol. 66–67, Nov. 6, pp. 379–381). The importance of blast-furnace slag and different ways of using it to make building materials are discussed.—R. A. R.

The Iron Industry and Agricultural Production. H. Kappen. (Stahl und Eisen, 1947, vol. 66–67, Nov. 6, pp. 381–384). The present position of the fertilizer industry in Germany is reviewed, and it is shown that the present production of fertilizers from slags and other by-products of the iron and steel industry falls far short of the demand.—R. A. R.

Old and New Binding Materials from Blast-Furnace Slag. F. Keil. (Stahl und Eisen, 1947, vol. 66–67, Dec. 4, pp. 416–420). The German Engineering Standards for cements are reviewed with a view to placing the binding materials made from blast-furnace slag in the series. The development, properties, and applications of new German binding materials made from slag are discussed.—R. A. R.

Utilisation of Blast Furnace Slag in Germany. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1476 : H.M. Stationery Office). Short accounts are given of the methods used at various German ironworks for the treatment of blast-furnace slag for the manufacture of road-making materials,

slag-wool, cement, plaster, etc. German standard specifications for the properties and testing of products made from blast-furnace slag are reproduced.—C. O.

PRODUCTION OF STEEL

Iron and Steel Industry in Russia. J. Alexandrovsky. (Hutnické Listy, 1946, vol. 1, No. 1, pp. 6–10; No. 2, pp. 34–37; No. 3, pp. 57–60: Engineering, 1948, vol. 165, Feb. 6, pp. 141–143). An account is given of the development of the iron and steel industry of the U.S.S.R. with data on the number, size, and present output of blast-furnaces and steel furnaces.—R. A. R.

The Selection of Samples for the Study of Manufacturing Processes for Steels. R. Zoja. (Ricerca Scientifica e Ricostruzione, 1947, vol. 17, July–Aug., pp. 1161–1164). —R. F. F.

The Revolution in Steel. H. W. McQuaid. (Metal Progress, 1948, vol. 53, Jan., pp. 67–74). Present and possible future trends in the American iron and steel industry are reviewed, and the influences of governmental policies, scrap and iron prices, improvements in electric-furnace refining, and better knowledge of the physical chemistry of steelmaking are outlined.—J. R.

Progress in Open-Hearth Valve Design. (Steel, 1948, vol. 122, Feb. 9, pp. 90–94). A description is given of the open-hearth reversing valve designed by H. Hellan. —R. A. R.

Some Features of Open Hearth Furnace Design. G. R. Bashforth. (British Steelmaker, 1947, vol. 13, Sept., pp. 446–454; Oct., pp. 502–511; Nov., pp. 554–563; 1948, vol. 14, Jan., pp. 34–41). Considerations affecting the dimensions and design of open-hearth furnaces and their accessories are presented and discussed. —J. R.

Operating Data on the Tilting Open-Hearth Furnace Process. A. Jackson. (Iron and Coal Trades Review, 1948, vol. 156, Feb. 6, pp. 259–261). An outline is given of the development of the tilting-open-hearth-furnace process in the Lincolnshire district since its introduction there in 1902. Results of full-scale tests on various fuels and other factors considered to have a bearing on production rates are presented and discussed.—J. R.

Open-Hearth Problems. C. R. FonDersmith. (American Institute of Mining and Metallurgical Engineers: Steel, 1948, vol. 122, Jan. 19, pp. 85–88). Various open-hearth developments and problems, including the use of basic refractories and oxygen, are briefly discussed. —J. R.

Open Hearth Charging Delays and Their Effect on Steel Production. J. A. Warchol, jun. (Blast Furnace and Steel Plant, 1947, vol. 35, Dec., pp. 1479–1481). The effects of charging delays on the melting and refining periods in the open-hearth furnace are discussed and factors for the attainment of minimum charging time are outlined.—J. R.

Oil-Fired Open-Hearth Furnaces at Outreau. Sinoquet. (Centre de Documentation Sidérurgique, Circulaire d'Information Techniques, 1947, vol. 4, July 25, No. 9/10, pp. 47–48). For some years the open-hearth furnaces at Outreau have been fired with a mixture of blast-furnace gas and light or heavy fuel oil. The pre-treatment of the oil and the method of injection into the furnace are briefly described.—J. C. R.

Oil-Fired Open-Hearth Furnaces at Pompey. Bettembourg. (Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1947, vol. 4, July 25, No. 9/10, pp. 49–59). The compositions of various fuel oils are given and their properties compared with those of gaseous fuels. Methods of atomizing the oil are explained and injectors and burners are described. Oil-fired furnaces are in operation at the Pompey steelworks and results obtained are compared with those of furnaces fired with coke-oven gas. Brief mention is made of the influence of the proportion of sulphur in the fuel oil on the quality of the steel produced.—J. C. R.

Production of Sulphur-Bearing Steels. Hauth. (Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1947, vol. 4, Oct. 15, pp. 41–44). Some practical considerations in the production of sulphur-bearing steels are outlined.—J. C. R.

Diffusion Phenomena during the Manufacture of Steel in a Basic Arc Furnace. R. Zoja. (Ricerca Scientifica e Ricostruzione, 1947, vol. 17, June, pp. 935–936: [Abstract] Chimie et Industrie, 1948, vol. 59, Feb. p. 155). Diffusion phenomena take place between slag and bath, and bath and lining in the basic arc furnace. Iron oxide is absorbed by the lining during oxidation and returned to the bath during reduction. The production of steel is affected by the presence of an "active layer" between metal and slag.—R. F. F.

Study on the Deoxidation of Steel by Vacuum-Fusion. J. Thomas and L. Moreau. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, July–Aug., pp. 204–207). Preliminary laboratory tests on the deoxidation of molten steel by carbon in a vacuum are described.—R. F. F.

PRODUCTION OF FERRO-ALLOYS

The Production of Ferromanganese from Low-Grade Ores. H. Reinfeld. (Stahl und Eisen, 1948, vol. 68, Jan. 29, pp. 39–43). Details are given of a long series of trials in the manufacture of 50% ferromanganese from siliceous lean manganese ores in a German blast-furnace. In this process large additions of dolomite were made so as to produce a highly basic easy-flowing slag which increased the proportion of manganese in the metal and reduced that in the ferromanganese slag. A successful process was developed in which 80% recovery of manganese was obtained.—R. A. R.

Tests Made at the Dniepropetrovsk Works with a Blast-Furnace Using an Enriched Air Blast. M. A. Chapovalov. (Kislorod, 1944, No. 1, pp. 17–31: Centre de Documentation Sidérurgique, Circulaire d'Informations Techniques, 1947, vol. 4, Mar. 25, No. 5, pp. 3–11). An account is given of tests carried out with a blast-furnace which produced ferrosilicon (10–11% silicon) at an average rate of 90 tons/day with a coke consumption of 2·3–2·4 tons/ton of metal produced. When the blast was enriched to 25–27% oxygen blast-furnace operation was normal and output increased to 160 tons/day while coke consumption went down to 2 tons/ton of output. When 33% of oxygen was used, scaffolding occurred in the blast-furnace and was cleared by reducing the temperature of the blast from 800° to 650° C. and reducing the oxygen content. However, output increased by 110–130 tons/day and coke consumption fell to 1·6 tons/ton of output. A slight increase in the silicon content of the ferrosilicon was noted. The effect of varying the oxygen content on the temperature inside the blast-furnace at different levels was also examined. The use of enriched blast in the production of other ferro-alloys and pig iron is discussed.—J. C. R.

The Problem of Pure Manganese: Electrothermic Refining of Ferro-Manganese; Chemical Balance. M. Deribéré. (Chimie et Industrie, 1945, vol. 54, Sept., pp. 172–176). Practical examples of the electrothermic refining of ferromanganese, using carefully computed charges, are described.—R. F. F.

FOUNDRY PRACTICE

The Simultaneous Use of Inorganic and Organic Binders. L. Jeníček. (Archiv für Metallkunde, 1947, vol. 1, Jan., pp. 76–83). The raw material situation in Germany has led to experiments in the use of mixed organic and inorganic binders for moulding sand. Data on the properties of sands prepared in this way are presented in a manner which enables mixtures to be prepared so that the product will have approximately the desired properties without too much loss of time on tests.—R. A. R.

Some Applications of Asbestos in the Foundry. F. J. McCulloch. (Institute of British Foundrymen : Foundry Trade Journal, 1947, vol. 83, Dec. 11, pp. 309–310). An outline is given of certain technical difficulties encountered in the production of (1) a large hydraulic cylinder, (2) a solid wheel with a chill-cored centre, and (3) light castings requiring thickening. The difficulties were overcome by the use of asbestos sheet or yarn, and the methods of application are described.—J. R.

A Strickled Core for a Lead Pot. W. Gudgeon. (Foundry Trade Journal, 1948, vol. 84, Jan. 1, p. 11). The production of a 4½-cwt pot casting to contain molten lead is described as an example of the use of strickles in the making of both the mould and the core. The mould was worked to the required design by sweeping the strickle round the spindle, and the core was shaped by the strickle-and-frame method.—J. R.

The Chipping Operation. R. E. Chapman. (Steel Founders' Society of America : Foundry, 1947, vol. 75, Nov., pp. 72–75, 228–238). After reviewing what is required of a chipping-shop foreman and his men, the types and capacities of the tools, the chipping operation, and safety precautions are discussed.—R. A. R.

Sealing of Porous Castings. A. Debecq. (Chimie et Industrie, 1946, vol. 56, Aug., p. 114). A method of sealing porous castings by impregnating with sodium silicate, is described.—R. F. F.

Salvage of Cast Iron through Heat Treatment. D. V. Ludwig. (Materials and Methods, 1947, vol. 26, Nov., pp. 87–89). A description is given of heat-treatment methods by means of which the scrapping of expensive and intricate high-grade iron castings originally rejected in inspection tests was obviated. It is suggested that the tendency of cast iron permanently to increase in volume when heated above its transformation range, usually regarded as an outstanding deficiency of this material, can be used to advantage in the production of precision parts from iron alloys.—J. R.

The Scientist in the Foundry. C. R. Tottle. (Institute of British Foundrymen : Foundry Trade Journal, 1947, vol. 83, Dec. 25, pp. 347–349). Suggestions are given for (1) the use of supersonic waves in the testing of castings and finished products, (2) the introduction of radio-active isotopes into the melt to facilitate the study of casting phenomena, (3) the fitting of "windows" in the moulds to permit visual, cinematographic, and pyrometric observations during casting, (4) the local alloying of wear-resistant parts in grey-iron castings, and (5) the relief of stresses by the mechanical removal of metal. —J. R.

Piece-Work (Standardizing) in General, and Piece-Work in Foundries. K. Stastný. (Hutnické Listy, 1947, vol. 2, No. 6, pp. 124–128). [In Czech.]

Foundry Conditions, Personnel and Production. R. F. Coates. (Foundry Trade Journal, 1947, vol. 83, Dec. 25, pp. 351–354 ; 1948, vol. 84, Jan. 1, pp. 3–8). The need for improvement in the standard of working conditions in foundries is discussed and it is emphasized that good physical and mental environments are important factors in the achievement of increased production. Examples are given of some initial measures which have proved successful, and suggestions for others are outlined. It is considered that, in addition to their effect on production, good working conditions in the foundry can result in the raising of the status of the industry and its personnel.—J. R.

HEATING FURNACES AND SOAKING PITS

The Evolution and Absorption of Hydrogen by Steel in Industrial Reheating Furnaces. J. Cameron. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 609–615).

Recirculation of Gases. E. Watkinson. (Institute of Fuel, 1947, Preprint). In furnace working at temperatures below 850° C. it is necessary to dilute the gaseous products of combustion in order to obtain the correct temperature. Several furnaces in which this dilution is brought about by the recirculation of part of the gas which has passed through the furnace are described, and their efficiency is calculated. The furnaces include : A direct-coal-fired air heater ; a coke-fired foundry mould and core drying stove ; a direct-gas-fired oven for the baking of lacquered products ; and a direct-oil-fired workshop air heater.—C. O.

Remote Control of Continuous Slab Heating Furnaces. C. E. Duffy. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 70–75). A description is given of the control equipment for four 18 × 80-ft. triple-zone continuous slab-heating furnaces at the Sparrows Point plant of the Bethlehem Steel Co. The instruments are housed some distance from the furnaces and the advantages of this arrangement are enumerated.—J. R.

Fuel Economy by the Thermal Insulation of Furnaces. J. Grosso. (Revue de Métallurgie, 1945, vol. 42, Jan., pp. 7–14). A method is given for measuring heat losses through furnace walls by drawing up a heat balance under "no-load" conditions, and methods are suggested for reducing these losses.—R. F. F.

Thermal Efficiency of Town or Coke-Oven-Gas-Fired Industrial Furnaces. J. Molinié. (Energie, 1947, vol. 31, Dec., pp. 289–296 ; 1948, vol. 32, Jan., pp. 13–18). Formulæ are given for the direct calculation of the thermal efficiency of gas-fired furnaces.—R. F. F.

Uses of Infra-Red Rays for Industrial Drying. M. Déribéré. (Chimie et Industrie, 1941, vol. 45, June, pp. 541–550). The efficacy of infra-red drying and its application to industry are discussed.—R. F. F.

"Infra-Red" Heating by Gas—Its Development and Practice To-day. J. B. Carne. (Metallurgia, 1947, vol. 36, Aug., pp. 193–196 ; Sept., pp. 245–249). The development and characteristics of industrial infra-red radiant heating are discussed. Typical applications are described and illustrated.—C. O.

Symposium on Soaking-Pit Operation. (Industrial Heating, 1947, vol. 14, Apr., pp. 602–604, 686 ; May, pp. 770–776). A summary is presented of the proceedings at a symposium on soaking-pit operation organized by the Engineers' Society of Western Pennsylvania.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The Effect of Carbon Content on the Hardenability of Boron Steels. G. D. Rahrer and C. D Armstrong. (American Society for Metals, 1947, Preprint No. 2). This paper concerns an investigation to determine the predominant factors influencing the hardenability of boron steels. Hardenability values are based on a

comparison of results from end-quench hardenability specimens representing 53 open-hearth boron steels and companion boron-free steels of substantially the same analyses. Compositions include plain carbon to medium alloy types with carbon contents from 0·12% to 0·95%. The results inducate that, with additions of boron in the 0·0006–0·0045% range, only carbon content and intensity of deoxidation affect the hardenability factor for boron. A simple factor for expressing the influence of boron on hardenability is given.—R. A. R.

Tempering Effects and the Mechanical Equation of State. J. C. Fisher and C. W. MacGregor. (American Society for Metals, 1947, Preprint No. 3). The idea of a " mechanical equation of state " (*see* Journ. I. and S.I., 1947, vol. 155, Feb., p. 310) is extended to include materials in which the processes of tempering is proceeding, and a formula is developed for expressing the degree of tempering in terms of tempering temperature and time. Tensile tests of the true stress-strain type on steel specimens tempered in the 705° to 370° C. range are described; the results showed that the tempering process is independent of strain.—R. A. R.

Report of Investigation at Stahlwerke Kabel C. Pouplier Jnr. at Hagen-Kabel. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S. Final Report No. 1590: H.M. Stationery Office). This is a report on the processes employed at the works of C. Pouplier, Jnr., at Hagen-Kabel where hardened, tempered, polished, and blued steel strip is made and cut to required lengths.—R. A. R.

German Hardened and Tempered Steel Strip Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1673: H M. Stationery Office). An account is given of German methods of producing hardened and tempered steel strip for saws, rule tape, razor blades, and clock springs.—R. A. R.

Quenching Billets and Bars Directly from Rolling at Ruhrstahl, Witten. (British Intelligence Objectives Sub-Committee, 1948, Miscellaneous Report No. 58: H.M. Stationery Office). This report describes experimental plant at Ruhrstahl A.G., Witten, for the quenching of billets and bars directly from the mill without reheating, as well as the results obtained with an electrical resistance furnace for tempering bars.—R. A. R.

Contribution to the Study of Work-Hardened Mild Steel Sheets—Heat-Treatment. J. Yourtaieff. (Revue de Métallurgie, 1946, vol. 43, May–June, pp. 162–168). The heat-treatment of open-hearth rimming steel sheets for stamping was studied. For stress relief, heat-treatment at 550° C. ± 50° for 20 to 30 min. is suggested; for annealing, 635° C. ± 15° for 10 to 30 min. (maximum time in furnace 40 min.); and for normalizing, 925° C. ± 25° for 7 to 15 min.—R. F. F.

The Heat Treatment of Spot Welds in Steel Plate. W. F. Hess, W. D. Doty, and W. J. Childs. (Welding Journal, 1947, vol. 26, Nov., pp. 641-s–652-s). An investigation is described the results of which show that it is possible to perform in the spot-welding machine all the common heat-treatments, including grain-refining, tempering, and austempering, and that the mechanical properties of the weld are thus greatly improved.—R. A. R.

Surface-Hardening and the Strength of Gear Wheels. H. Glaubitz. (Werkstatt und Betrieb, 1947, vol. 80, Oct., pp. 249–259; Nov., pp. 277–282). The following methods of hardening gear teeth are briefly described: (1) Pack-carburizing; (2) cyanide-bath hardening; (3) nitriding; (4) neutral-salt-bath hardening; (5) flame-hardening; (6) induction hardening; and (7) quench-hardening. Details are then given of methods of measuring tooth wear and the bending, fatigue, and impact strengths of teeth. Finally, the results are given of a comprehensive investigation of the wear-resistance and mechanical properties of teeth hardened by the above methods.—R. A. R.

Salt Bath Annealing Proves Fast and Versatile. E. L. McReynolds. (Wire and Wire Products, 1947, vol. 22. Nov., pp. 883–884, 916). A description is given of an electrically heated salt-bath installation for annealing coils of small rolled sections. The inside dimensions of the bath are 60 × 57 × 60 in. It is a 175-kW. unit heated by immersed electrodes.—R. A. R.

A New Batch-Type Gas Cyaniding Furnace. J. A. Dow. (Metal Progress, 1947, vol. 52, Dec., pp. 984–987). A convection-heated bath-type gas cyaniding furnace is described. The gas-fired radiant tubes of the furnace are surrounded by refractories of high specific heat, which act as a heat accumulator, giving a very rapid initial transfer of heat to the charge. The gas generator is designed to give continuous automatic adjustment of the furnace atmosphere.—C. O.

Heating Rates in Electric Furnaces. G. B. Lamb. (Machinery, 1947, vol 71, Dec. 11, pp. 661–663). A short investigation of the heating rates of mild-steel bars of various sizes in an electric furnace on a small scale is described, and appropriate heating curves evolved. It is expected that for articles of non-circular section the heating times will be similar to those for round bars. —R. L. B.

Electric Resistance Type Appliances. V. Paschkis. (Industrial Heating, 1947, vol. 14, Sept., pp. 1432–1444, 1448). The principles and principal types of electric heating appliances which have no chamber for the charge or are not completely thermally insulated are described. The appliances are of two kinds—direct, in which the object to be heated forms part of an electric circuit (*e.g.*, rivet-heaters) and indirect, in which heat is generated by electrical resistors (*e.g.*, immersion heaters).

Controlled Vacuum Heat Treating. (American Gas Association: Steel, 1947, vol. 121, Nov. 24, pp. 80–83. 96–107). Tests are described in which specimens of cast iron and steel were heat-treated *in vacuo* and in various atmospheres. First an iron (C 2·54%, Si 1.26%) was malleablized *in vacuo*, in DX gas (CO_2 5%, CO 10%, H_2 12%, H_2O 3%, N_2 70%), RX gas (CO 20%, H_2 40%, N_2 40%), cracked ammonia, and nitrogen. The completeness of the anneal, as measured by the ductility, decreased with increasing hydrogen in the atmosphere. The best results were obtained *in vacuo*. Experiments were made on steel to establish the effects of nitrogen, hydrogen, and oxygen on the rate of diffusion of carbon. This rate was practically unaffected by the atmosphere or by dissolved gases when present in normal amounts. Another series of tests indicated that the reaction of a hydrocarbon gas with steel to form iron carbide was not dependent on the catalytic effect of oxygen. In general, no benefit resulted from heat-treatment *in vacuo* as compared with other methods. —R. A. R.

Applications of the Science of Gas Chemistry to Heat Treating Processes. O. E. Cullen. (American Gas Association: Industrial Heating, 1947, vol. 14, Sept., pp. 1450–1458). A brief review is made of the uses of controlled atmospheres in carbon restoration, hot working, gas carburizing, and cyaniding.—C. O.

Symposium on the Peeling of Whiteheart Cast Iron. (Journal of The Iron and Steel Institute, 1948, vol. 158, Jan., pp. 1–36). The failure of track links in military vehicles reached serious proportions during the 1939–45 war owing to the " peeling " of whiteheart malleable castings. In the introduction, J. C. W. Humfrey explains

that the purpose of the present symposium is to collect the results of the researches and show how the true cause of peel was established and the way pointed for its elimination. Titles of the papers follow.—R. A. R.

The Formation of Peel on Whiteheart Malleable Cast Iron. A. Preece and K. J. Irvine. (*Ibid.*, pp. 3–8).

Peel on Whiteheart Malleable Cast Iron. J. S. Bowden. (*Ibid.*, pp. 9–14).

Peeling of Whiteheart Malleable Iron. G. R. Webster and A. E. Probst. (*Ibid.*, pp. 15–19).

Experimental Work Carried Out at the British Cast Iron Research Association. J. Bernstein. (*Ibid.*, pp. 20–36).

Modern Malleable Cast Iron Abroad (from Foreign Technical Reports). H. Hermanns. (Technik, 1947, vol. 3, Nov., pp. 483–488). The manufacture, microstructure, and properties of whiteheart and blackheart malleable iron are discussed, and modern annealing procedures are described in detail.—R. A. R.

The Effect of Homogenization on Cast Steels. R. J. Marcotte and C. T. Eddy. (American Society for Metals, 1947, Preprint No. 30). The effects of homogenization heat-treatments on the hardenability, the impact properties and the time-temperature-transformation curves for certain selected cast steels were studied. Standard testing procedures were employed throughout. The investigation revealed that for the steels studied and for the time and temperatures of homogenization employed, the effects on the mechanical properties, attributable solely to homogenization, are negligible. —R. A. R.

Facilities for Handling Variety of Parts Features Production Heat Treating at Atwood Vacuum Machine Co. L. C. Smith. (Industrial Heating, 1947, vol. 14, Nov., pp. 1844–1852, 1862). Illustrated descriptions are given of the heat-treating equipment for automobile and lawn-mower parts at the Atwood Vacuum Machine Co., Rockford, Illinois.—R. A. R.

Flame Hardening of Armor Plate. E. L. Bartholomew, jun., M. S. Burton, and F. R. Evans. (Metal Progress, 1947, vol. 52, Dec., pp. 979–983). The results of investigations of problems encountered during the flame-hardening of flat weldable low-alloy armour plate are presented. Using a 6-in. wide torch it was possible to obtain a case of uniform depth 0·25–0·30 in. deep, of hardness 510 V.D.H. on 0·24–0·31% carbon steel. However, a soft tempered zone was always obtained where successive passes of the torch overlapped. In thin plates excessive warping was experienced, the hardened surface becoming concave. Attempts to straighten warped plates were unsuccessful.—C. O.

Flame Hardening Locomotive Brake and Spring Rigging Pins and Bushings. B. W. Covell. (Welding Journal, 1947, vol. 26, Oct., pp. 918–922). An illustrated account is given of practical experience of the flame-hardening of locomotive brake and spring parts.—C. O.

High-Frequency Heating. (Iron and Steel, 1947, vol. 20, Dec., p. 652). A description is given of Czechoslavakian equipment for the heat-treatment of comparatively small parts on a mass-production basis by means of a 200-kW. high-frequency generator coupled to one or more induction-heating units. The generator is also available in 5, 20, 50, and 100-kW. ranges, and examples of the high output rates and savings in costs achieved are quoted.—J. R.

Induction Hardening of a Quality Controlled Iron. C. F. Walton and H. B. Osborn, jun. (American Society for Metals, 1947, Preprint No. 4). The ready response of the as-cast structure of Meehanite makes it very suitable for the short heating cycles inherent with the use of induction heating. A matrix devoid of free ferrite and consisting of either fine pearlite, or sorbite and pearlite, permits practically instantaneous solution of the carbide.—R. A. R.

Some Factors Affecting the Induction Hardening of an Alloy Cast Iron. J. R. Sloan and R. H. Hays. (American Society for Metals, 1947, Preprint No. 5). The induction-hardening of the bore surface of grey cast-iron cylinder liners, utilizing frequencies of 3000 and 9600 cycles/sec. is discussed. Power inputs were varied for the 9600-cycle current. An unexpected variance in results, when compared with similar treatments for steel, indicated that additional factors are being introduced which have a considerable effect on the physical properties. The higher frequency concentrates the heat energy input closer to the surface with a consequent increase in temperature. For a medium carbon steel, this overheating produces a coarsening of structure, grain growth, and a reduction in physical properties.—R. A. R.

Long Pieces Can Be Induction-Hardened Progressively. F. W. Curtis. (Machinist, 1948, vol. 91, Jan. 10, pp. 1254–1256). Equipment for induction-hardening long bars, blades, and other parts is described and illustrated. The machines make provision for feeding the part through the heating coil and quenching ring at a predetermined rate. Less power and a smaller coil are required than when the whole of the part is heated simultaneously, and there is usually less distortion.—R. A. R.

Basic Requirements of Materials for Induction Hardening. R. H. Lauderdale. (Machinist, 1947, vol. 91, Dec. 27, pp. 1181–1183). The induction-hardening of steel is discussed under the following headings: Power requirements; initial microstructure; size and shape of parts; carbon content; dimensional changes; and subsequent processing.—C. O.

Universal Control of Induction Heater. A. B. Shields. (Machine Design, 1947, vol. 19, Sept., pp. 147–148). An electronic device for controlling the heating, quenching, and timing operations in an induction-hardening apparatus is described and illustrated.—C. O.

High Frequency Furnaces. A. de Saint-Andrieu. (Fonderie, 1946, Apr., pp. 143–155). After a review of the various types of electric furnace in use, an account is given of the principles of the high-frequency furnace, its industrial applications, advantages, and limitations. A detailed description of a 250-kW. furnace of this type is given.—J. C. R.

Continuous *versus* Batch Annealing of Sheet and Strip. T. F. Olt. (Iron and Steel Engineer, 1947, vol. 24, Nov., pp. 52–64). The continuous and batch methods of annealing sheet and strip steel are compared, from the points of view of the metallurgical properties produced, heat requirements, and cost. It is considered that the continuous, or "normalizing" method is appreciably dearer in fuel, labour, and equipment, except perhaps when associated with continuous cleaning or coating processes, and that normalized sheets only approach the drawability of cold-reduced box-annealed sheets if subjected to a box-annealing after normalizing.—C. O.

Use of Modified Martempering for Hardening Intricately-Shaped Dies. W. Olson and G. Nevins. (Steel, 1947, vol. 121, Dec. 15, pp. 88–89, 115). Tests of a modified martempering process for the hardening of manganese–chromium–tungsten steel press dies are reported. Satisfactory results, with freedom from cracking and little growth were obtained by heating to 1475° F., martempering in hot oil (250–280° F.), and tempering at 400° F.—C. O.

The Tempering of Steel. F. H. D. Robinson. (Australian Institute of Metals: Australasian Engineer, 1947, Nov. 7, pp. 77–85). A general account is given of the principles of the tempering of quenched steel.—C. O.

Use of Sub-Zero Temperatures for Treating and Assembling Metal Parts. G. B. Olsen. (Machinery, 1948, vol. 72, Jan. 8, pp. 43–45). Metallurgical applications of sub-zero heat-treatment are indicated. They include dimensional stabilization, the improvement of the performance of Carboloy cutting tools by cooling with a stream of compressed sub-zero-cooled air, and the hardening of high-speed steels.—C O.

FORGING, STAMPING, DRAWING, AND PRESSING

German Practice in Fabrication of Gas Turbine Blades. (British Intelligence Objectives Sub-Committee, 1948, F.I.A.T. Final Report No. 1129: H.M. Stationery Office). Three methods used at Bayrische Motoren Werke for fabricating blades for gas turbines out of an austenitic chromium-manganese steel are described. —R. A. R.

Importance of Lubrication in Forging Operations. A. F. Brewer and J. C. Van Gundy. (Steel, 1947, vol. 121, Dec. 1, pp. 92–95, 102–109). Factors influencing the selection of the lubricant and lubrication system of heavy forging presses and hammers are discussed and several systems are described.—R. A. R.

Tyre, Tube and Heavy Plant Manufacture. (Appendix No. 14a to C.I.O.S. Report XXXII-119). (British Intelligence Objectives Sub-Committee, 1947, File No. XXXIII-71: H.M. Stationery Office). Brief accounts, illustrated by photographs, are given of the general state of the plant at the works of Bochumer Verein, Mannesmann, Rohrenwerke, Demag, and Sachs.— —R. A. R.

Hydraulic Forming of Stainless Steel. W. C. Brice. (Materials and Methods, 1947, vol. 26, Nov., pp. 68–70). The production of one-piece milk pails approximately 12 in. in dia. and 18 in. high from a stainless steel of the 18/8 type was complicated by the requirement that the tops of the pails should be necked-in slightly. The problem was finally solved by the use of internal hydraulic pressure to force the metal into the desired shape between a non-mating and a female die, the latter acting as a sealing agent.—J. R.

The Use of Rubber Dies in Producing Laminations from Electrical Steel Sheets. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S. Final Report No. 1527: H M. Stationery Office).

Shaping and Forming. W. Trinks. (Yearbook of the American Iron and Steel Institute, 1947, pp. 416–445) *See* Journ. I. and S.I., 1947, vol. 157, Nov., p. 470.

Practical Problems of Light Presswork Production. J. A. Grainger. (Sheet Metal Industries, 1947, vol. 24, Jan., pp. 95–99; Feb., pp. 321–328; Mar., pp. 549–532; Apr., pp. 761–768; May, pp. 965–966, 970; June, pp. 1167–1170, 1174; July, pp. 1369–1376; Sept., pp. 1789–1795; Nov., pp. 2214–2216). Continuation of a series of articles (*see* Journ. I. and S.I., 1947, vol. 155, Apr., p. 631).—R. A. R.

Fabricating Steel Hardware. (Steel, 1947, vol. 121, Dec. 22, pp. 71–72, 86–88). The hot and cold-working methods used by the Oliver Iron and Steel Corporation, Pittsburgh, in the manufacture of steel bolts and other types of fastener are briefly outlined.—C. O.

Improved Production in Drawing with Tungsten Carbide Dies. (Sheet Metal Industries, 1947, vol. 24, Dec., pp. 2425–2426). Brief accounts are given of increases in die-life achieved in various metal-drawing operations by the use of tungsten carbide dies.—C. O.

Carbide Sheet Metal Dies. E. Glen. (Steel Processing, 1947, vol. 33, Oct., pp. 618–621). Several types of progressive dies, drawing dies, blanking dies, and punches made of sintered carbides and the operations performed by them are described and illustrated.—R. A. R.

Wire Liming—Suggestions for Improvement. (Wire Industry, 1947, vol. 14, Dec., p. 688). The efficiency of lime coatings for wire drawing is discussed. The lack of neutralizing power of lime is considered to be a serious limitation, and the possibility of using glycerine, or compounds containing caustic soda, potash, borax, or soda-ash, in the place of conventional lime coating is examined.—C. O.

A Theoretical Analysis of the Stresses and Strains in Wire-Drawing. R. Hill and S. J. Tupper. (Ministry of Supply, Armament Research Department Report No. 10/47, July, 1947). A new theory, based on a two-dimensional plane strain model is proposed to describe the stress distribution in a wire drawn through a die. The calculated stresses are found to agree closely with experimental data, for conditions of axial symmetry. A simple method is suggested for evaluating the drawing stress of a metal having any stress/strain curve. The influence of friction, "bulging" of the metal in front of the die, and the deformation of a grid ruled on a cross-section of a wire are also considered.—C. O.

Wire-Drawing in Continuous Drawing Machines. S. Geleji. (Hungarian Palatine Joseph University, Publications of the Department of Mining and Metallurgy, 1944–47, vol. 16, pp. 45–58). The theory of wire-drawing and the design of wire-drawing machines is discussed, and formulæ are developed for calculating the forces involved.—R. A. R.

World Wide Wire Industry—Germany, War-Time Progress in German Wire Mills. H. Hermanns. (Wire and Wire Products, 1947, vol. 22, Nov., pp. 901–903). Technical progress in German wire mills in the period 1939–45 is reviewed.—R. A. R.

WELDING AND FLAME-CUTTING

Oxy-acetylene Grooving. R. Pappi. (Revue de la Soudure: Laschtijdschrift, 1947, vol. 3, No. 3, pp. 107–118). An oxy-acetylene method of cutting grooves in preparation for welds is suggested and some applications are given.—R. F. F.

Flame Deseaming. F. Judelsohn. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 51–54). The economics and advantages of torch deseaming are discussed and some of the results obtained are illustrated.—J. R.

Oxyacetylene Powder Cutting and Scarfing. D. H. Fleming, jun. (International Acetylene Association: Steel, 1947, vol. 121, Dec. 1, pp. 96–97, 120–126). The technique for cutting stainless and other high-alloy steels with an oxy-acetylene flame in which a stream of iron powder is entrained is described with data on cutting speeds and consumptions of the gases and powder. Scarfing steel ingots by this process is also described and discussed.—R. A. R.

Unique Canadian Contributions to Oxygen Cutting. R. A. Dunn. (Canadian Metals and Metallurgical Industries, 1947, vol. 10, Oct., pp. 16–19). Oxy-acetylene cutting techniques which were introduced in Canada for the manufacture of large and small gun parts are described. They include a low-oxygen-pressure technique for cutting alloy steel billets 13 to 14 in. thick, and solenoid-operated valves for turning the gases off and on for some of the machines.—R. A. R.

The Theory of Oxyarc Cutting. H. C. Campbell. (Welding Journal, 1947, vol. 26, Oct., pp. 889–903). The Oxyarc process is a method of cutting, piercing, or gouging, employing an electric arc and a stream of

oxygen, the latter flowing through the flux-coated tubular electrode. The mechanism of the cutting of mild steel is analysed by the author, and shown to conform to simple rules based on the theoretical heat-distribution curves established for ideal arc-welding conditions. The rate of burn-off of the electrode is proportional to the current and the cross-sectional area of the core, and the rate of cutting is proportional to the rate at which the kindling temperature is established on the surface of the plate. The mechanism of cutting oxidation-resistant metals is more complex, involving melting, diluting, fluxing, and mechanical ejection.—C. O.

POWDER METALLURGY

The "Construction of Alloys" as a Powder-Metallurgy Problem. G. Ritzau. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 305–307). The molecular structure of alloys and the relation between the dispersion of the components and the grain-size, hardness and strength are considered. The possibilities of "building up" useful magnetic materials of the Fe–Cu/Co–WC/Fe–Al_2O_3 system are discussed.—R. A. R.

Sintered Agglomerates of Metals and Non-Metallic Materials, Preferably Oxides. F. Skaupy. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 307–308). The manner in which the properties of metals can be modified by using the powder-metallurgy process to produce agglomerates from metallic and non-metallic powders is discussed.—R. A. R.

Development of a Heat-and Flame-Resisting Material of Low Specific Gravity. J. Bingel. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 309–311). The development by the powder-metallurgy process of materials suitable for gas-turbine blades and the jets of jet engines is discussed. For turbine blades the composition Cr 3%, Co 6%, W 2%, TiC 5%, SiC 84%, is proposed and for jets the composition Fe 10%, TiC 2%, SiC 88%.—R. A. R.

Technical Definitions in Powder Metallurgy. H.-J. Bartels, W. Hotop, and R. Kieffer. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 311–315). Nomenclature for the processes involved in powder metallurgy is discussed and an alphabetical list of German terms with definitions is presented.—R. A. R.

The Fundamentals and Laws of Crushing with Special Reference to Metals. E. Podszus. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 318–322).

The Technology of Sintered Iron. H. Wiemer. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 323–326). The effects of the initial structure of the soft iron powder and the pressure applied on the mechanical properties and density of cold-pressed parts are discussed. A diagram is constructed from laboratory-test data which relates the carbon content and density to the tensile strength, elongation and Brinell hardness of the product. The fatigue strengths of sintered iron and sintered steel are also considered.—R. A. R.

The Production of Iron Powder and Its Application. F. Eisenkolb. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 327–335). Descriptions are given of the following methods of producing iron powders: (1) Mechanical crushing; (2) granulating molten iron; (3) dry reduction of oxides; (4) electrolytic, and (5) recovery of solid iron from the gas phase. The principal method used in Germany is crushing in the Hametag mill. Test data on products made by various processes are compared, and applications of iron-powder-metallurgy products are considered.—R. A. R.

The Production for Powder Metallurgy of Iron Powder from Very Pure Iron Ore Concentrates. W. Luyken and H. Kirchberg. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 335–345). Investigations on Swedish magnetites showed that, by wet-mechanical methods, the ore could be crushed to — 0·25 mm. powder containing 0·36% max. of SiO_2. This crushed ore could be reduced in hydrogen at 600–650° C. to iron powder containing 0·7–1·5% residual oxygen. Finished parts made with this material by powder metallurgy had excellent properties.—R. A. R.

The Development of Powder-Metallurgy Bearings. F. Eisenkolb. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 345–352). The development of bearings by the powder-metallurgy process is traced, and an account is given of many tests to establish the optimum conditions of manufacture and the loads which the bearings can take. A list of the trade names of German bearings is given.—R. A. R.

Powder-Metallurgy Materials in the Production of Plain Bearings. St. Fronius. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 352–356). The oil-retaining properties of powder-metallurgy bearings are considered, and the results of many tests correlating data on bearing loads, coefficients of friction, running speeds, and temperatures are presented.—R. A. R.

Investigations on the Reduction in the Contents of Carbon, Sulphur, and Oxygen during the Sintering of Iron Powder in a Hydrogen Atmosphere. G. F. Hüttig. (Archiv für Metallkunde, 1947, vol. 1, July–Aug., pp. 359–361). Experiments are described, the results of which indicate the effect of sintering temperature on the reduction of the carbon, sulphur, and oxygen contents of iron compacts in the powder-metallurgy process. It is possible to reduce the oxygen content without lowering the carbon content at temperatures below 500° C., but this does not reduce the oxygen in oxide inclusions. A sintering atmosphere containing carbon monoxide or hydrocarbon gases is recommended. The advantages and disadvantages of adding chlorides to the powder, or chlorine compounds to the sintering atmosphere, are discussed.—R. A. R.

Powdered Metal Filters. H. Seymour. (Mining Magazine 1947, vol. 77, Oct., pp. 206–208). Up to the present copper-base materials, chiefly bronze, have been used for the production of powdered-metal filters for the chemical industry, but stainless-steel filters are now available and can be used with a wide variety of acids, alkalies, and salts. Certain types can be made with tensile strengths as high as 30,000 lb. per sq. in., the minimum rating being 5000 lb. per sq. in. for the coarsest grades. The filters are made with average pore openings ranging from 0·0065 in. down to 0·00015 in., and are produced from the 18/8 composition, but for special service conditions copper and molybdenum are added.—R. E.

PROPERTIES AND TESTS

Energy Measurement in the Impact Fracture of a Notched Rail Test-piece. M. Perry. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, Nov.–Dec., pp. 336–346). In order to compare the elasticity of various types of rails, equipment was designed using the principle of measuring the energy required to break a notched specimen at a single blow. Two of these testing machines used by the Société des Hauts-Fournauex de la Chiers and the French State Railways are described and compared. For rails of high elasticity, results show an error usually less than 2% and never more than 5%. Advantages, disadvantages, and precautions needed with this method are discussed.

Explosive Impact Tests. P. R. Shepler. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 5, pp. 1–25). Apparatus is described which was set up at Massachusetts Institute of Technology to obtain fracture-stress/time and acceleration/time curves at fracture rates of the order of 10,000 to 25,000 in./0·1 sec. These rates were obtained by exploding gunpowder behind a piston which rested against the shoulder at the free end of the specimen. A load gauge was attached to the fixed end of the specimen. Eight ferrous metals and annealed copper were tested. The following conclusions apply for tests at room temperature and for uniaxial tension: (1) In all cases the strength increased with strain rate; (2) in all cases except a cast steel, the ductility, as measured by reduction in area, increased with strain rate; and (3) in all cases except a cast steel, the energy of deformation increased with strain rate.—R. A. R.

Theory of the Yielding and Plastic Flow of Anisotropic Metals. R. Hill. (Ministry of Supply, Armament Research Department, Report No. 4/47, July, 1947). A theory is proposed to describe, on the macroscopic scale, the yielding and plastic flow of a metal showing anisotropy such as results from preferred orientation or fibre texture due to cold work. A yield criterion, similar in form to the Huber-Mises criterion for isotropic metals, is postulated. Associated relationships are worked out between the stress and strain increment tensors, using von Mises' concept. The characteristic directions for states of plane stress and strain are shown to correspond to directions of zero extension. The theory is applied to experiments on the necking under uni-axial tension of flat bars cut from rolled sheet and pure torsion of a thin-walled cylinder.

X-Ray Determination of the Deformation of Single Crystals in Polycrystalline Metals. Adéla Kochanovska. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, July–Aug., pp. 192–197). In order to investigate the anisotropy of metals, tests were carried out on three specimens of steel. The measurements were taken using the K_α rays of cobalt, chromium and iron. Silver was used as a standard and aluminium in some cases as a control. The first specimen was annealed, but the other two were subjected to heat-treatment which caused deformation.—R. F. F.

Fatigue and Bauschinger Effect. P. Laurent and M. Ferry. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, Nov.–Dec., pp. 327–329). Dehlinger's theory is critically discussed, the authors basing their arguments on the interaction of crystals and the Bauschinger effect.—R. F. F.

The Influence of Intergranular Boundaries on the Deformation of Metals, Application to Creep and Fatigue. C. Crussard. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, Nov.–Dec., pp. 307–317). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 649.

A Numerical Solution for the Torsion of Hollow Sections. E. C. Colin, jun., and N. M. Newmark. (Journal of Applied Mechanics, 1947, vol. 14, Dec., pp. A-313–A-315). This paper describes a numerical method for solving directly the problem of the torsion of a bar of constant cross section having one or more internal longitudinal holes. The method involves the use of finite differences and can be used with either the iteration procedure due to H. Liebmann or the relaxation procedure attributed to R. V. Southwell.—R. A. R.

The Permanent Strain in a Uniform Bar Due to Longitudinal Impact. M. P. White and LeVan Griffis. (Journal of Applied Mechanics, 1947, vol. 14, Dec., pp. A-337–A-343). A method is presented for predicting the final strained state of a long uniform bar or wire of ductile material that is subjected to a longitudinal impact of finite duration during which the impact stress is constant and exceeds the yield strength. It is shown that for a long specimen this corresponds to giving the point of impact a constant velocity during the impact interval.—R. A. R.

On the Use of Power Laws in Stress Analysis Beyond the Elastic Range. Alice Winzer and W. Prager. (Journal of Applied Mechanics, 1947, vol. 14, Dec., pp. A-281–A-284). In a recent paper A. A. Ilyushin drew attention to the remarkable simplicity which the theory of plastic deformation assumes when the secant shear modulus is taken as a power of the octahedral shearing stress. In the present paper Ilyushin's results are discussed in connection with a specific example and it is shown that great caution is necessary in the use of such power laws.—R. A. R.

Effect of Temperature Gradients upon the Introduction of Residual Stresses in Weldments or Other Structures. J. R. Stitt. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 5, pp. 67–70). Specifications for the thermal stress-relieving treatment of welds differ in regard to the cooling rates. Calculations in this paper show that a difference of 170° F. between the maximum and minimum temperatures during the cooling of mild steel will produce a yield-point stress, and a greater difference will cause plastic flow.—R. A. R.

Recent Contributions to the X-Ray Method in the Field of Stress Analysis. J. T. Norton and D. Rosenthal. (Proceedings of the Society for Experimental Stress Analysis, 1947, vol. 5, pp. 71–77). Progress in X-ray apparatus and methods for stress analysis since a paper by the authors in 1944 (*see* Journ. I. and S.I., 1945, No. II, p. 92A) are reported. A technique for measuring stress at the bottom of a notch is described, and in an appendix D. Rosenthal explains the principles on which it is based.—R. A. R.

A Statistical Investigation of the Deformation of Cold-Rolled Metals and Alloys. L. Szöke. (Hungarian Palatine Joseph University, Publications of the Department of Mining and Metallurgy, 1944–47, vol. 16, pp. 20–25). Tests on 18/8 stainless steel demonstrated that there is a linear relationship between the deformation of a test-piece as a whole, and the average deformation of crystal grains.—M. A. V.

A Testing Machine for Producing Alternating Tension and Compression. E. Erlinger. (Métaux, Corrosion, Usure, 1942, vol. 17, Nov., pp. 209–214). An account is given of an alternating tension-compression testing machine originally described in Archiv für das Eisenhüttenwesen, 1937, vol. 10, Jan., pp. 317–320. (*See* Journ. I. and S.I., 1937, No. I, p. 234A). Modifications to the original machine are described.—J. C. R.

Fatigue Limit of Chromium Plated Steel. L. Mehr, T. T. Oberg, and J. Teres. (Monthly Review of the American Electroplaters' Society, 1947, vol. 34, Dec., pp. 1345–1359). A systematic investigation of the effects of plating variables on the fatigue limit of chromium-plated steel is reported. It was found that: (1) The minimum reduction in fatigue strength for plating up to 0·001 in. thick, without nitriding, was 8%, the maximum more than 50%; (2) optimum fatigue strength was obtained with plate applied at 55° C. in the upper end of the bright plating range; (3) the least favourable bath conditions were a low current density and a temperature of 70° C.; (4) in general, the higher the current density, the smaller was the decrease in fatigue strength; (5) nitriding before plating was beneficial; and (6) electrolytic polishing before plating led to a marked decrease in the fatigue limit of steel.—C. O.

The Influence of the Shape and Dimensions of the Test Piece on Fatigue Test Results. P. Laurent. (Comptes Rendus, 1947, vol. 224, Mar. 10, pp. 719–721). The author shows that the theory of consolidation of stresses justifies the opinion that the shape and dimension of the test-piece influence fatigue test results.—J. C. R.

Bibliography on the Fatigue Properties of Cast Iron. G. R. Woodward. (Bulletin of the British Cast Iron Research Association. 1947, vol. 9, Nov., pp. 59–63). Fifty-four references to the literature on the fatigue properties of cast iron are given, covering the period 1926 to 1947.—R. E.

Shot Peening Increases Life of Machinery Parts. R. B. Huyett. (Steel Processing, 1947, vol. 33, Sept., pp. 553–557, 573; Oct., pp. 609–613, 638, 647). Examples are given of instances in which the fatigue life of components made from metals of high elasticity may be increased by prestressing their surfaces in compression by shot-peening. The "Almen" gauge for measuring peening intensity, the control of peening operations, and centrifugal and air-blast shot-peening machines are described.—R. A. R.

An Appraisal of Hardenability Band Specifications for Alloy Steel. D. H. Ruhnke. (Yearbook of the American Iron and Steel Institute, 1947, pp. 580–596). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 304.

Hardenability. P. R. Wray. (Iron Age, 1947, vol. 160, Dec. 11, pp. 84–89). The principles of hardenability are simply explained. The derivation and functions of hardenability bands are discussed and illustrated by examples.—C. O.

On the Relation of Brinell, Vickers, and Cone Hardness. J. A. Verö. (Hungarian Palatine Joseph University, Publications of the Department of Mining and Metallurgy, 1944–47, vol. 16, pp. 3–19). Using a 2·5-mm. steel ball, a Vickers and a Rockwell hardness-testing instruments, tests were made on iron, copper, aluminium, and their alloys in order to establish a relationship between these methods. The results are discussed.

The Theory of Indentation and Hardness Tests. R. F. Bishop, R. Hill, and N. F. Mott. (Ministry of Supply, Armament Research Department, 1944, Theoretical Research Report No. 41/44). A discussion is given of the indentation of ductile materials by cylindrical punches with conical heads. On the experimental side, experiments have been made with work-hardened and with annealed copper, with penetrations up to nine times the diameter of the punch.—R. A. R.

The Theory of Combined Plastic and Elastic Deformation with Particular Reference to the Deformation of a Thick Tube under Internal Pressure. E. H. Lee, R. Hill, and S. J. Tupper. (Ministry of Supply, Armament Research Department, 1945, Theoretical Research Report No. 5/45). In certain problems of plastic flow, for example autofrettage of a gun tube, it is important to consider changes in the elastic strain of material which is flowing plastically in order to deduce the correct stress distribution and deformation. The usual plastic theory which neglects elastic strains in the plastic region may lead to considerable errors in certain cases. In this report a review is made of the theory of the deformation of a material under combined stresses which involves both elastic and plastic components of strain.—R. A. R.

The Theory of Wedge Indentation of Ductile Materials. R. Hill, E. H. Lee, and S. J. Tupper. (Ministry of Supply, Armament Research Department, 1945, Theoretical Research Report No. 10/45). The theoretical solution for the deformation produced by a rigid frictionless wedge penetrating a plastic material is presented in this report. The solution determines the form of the lip and the deformation in the material squeezed out towards the surface. The variation with wedge angle of the force required for penetration is determined in terms of the yield stress in a tensile test.—R. A. R.

The Theory of the Extrusion of Metals. R. Hill. (Ministry of Supply, Armament Research Department, 1945, Theoretical Research Report No. 23/45). The mechanics of the extrusion of metals has been the subject of much experimental work over the last thirty years, resulting in a general understanding of the deformation involved and in the construction of empirical formulæ relating the extrusion pressure and the extrusion ratio. There appears, however, to be no comprehensive theoretical analysis of the process based on the fundamental laws governing the plastic flow of metals. The object of this report is to take the first step in this direction by analysing in detail the two-dimensional problem of sheet extrusion. None of the essential features of the process are lost by this simplification. The two cases of direct and inverted extrusion are dealt with, the extrusion pressure being evaluated in terms of the extrusion ratio and the compressive yield stress of the metal at the temperature and average speed of working.—R. A. R.

The Two-Dimensional Theory of Plastic Yielding of Deeply-Notched Bars in Tension. R. Hill. (Ministry of Supply, Armament Research Department, 1946, Theoretical Research Report No. 9/46). The stress distribution in the core of a notched bar under tension is analysed at the stage when the bar is about to yield. This happens when a plastic region has just spread right across the core, and it corresponds to the first bend in the load-strain curve. It is assumed that the material is ductile, and has a fairly well-defined yield point in the ordinary tension test. A two-dimensional theory is used, but as the results are of roughly the same magnitude as those found experimentally for round bars, it seems that this does not greatly detract from the practical value of the theory. The greatest constraint factor found theoretically is about 2·57; this corresponds to a deep parallel-sided notch with exceedingly small root radius. Somewhat greater constraint can possibly be obtained with notches of keyhole shape.—R. A. R.

General Methods of Solution of the Axially Symmetric Problem in Plasticity. R. Hill. (Ministry of Supply, Armament Research Department, 1946, Theoretical Research Report 10/46). Various methods are discussed for solving axially symmetric problems in the plastic flow of metals under large strains. Three different lines of attack are developed in detail: (1) A direct approach based on the formulation of linear differential relations in the stresses and velocities along slip-lines and stream-lines; (2) an inverse method of generating solutions for use with the equations expressed in cylindrical co-ordinates; (3) the use of a variational principle of maximum plastic work. Examples are given of the practical application of each method.—R. A. R.

Machinability of a Standard Machine Steel. J. Erb and E. J. Weller. (Steel Processing, 1947, vol. 33, Oct., pp. 622–623). The results are given of a series of machining tests on a machining steel (C 0·18%, Mn 0·40%, Si 0·25%, P 0·40%, S 0·050%), specimens of which were heat-treated in various ways.—R. A. R.

Some Properties of Iron-Silicon Alloys Produced from Powders. R. Steinitz. (Powder Metallurgy Bulletin, 1947, vol. 2, Nov., p. 137). Alloys containing 1·5%, 4%, and 6% of silicon were produced from powders by sintering for 90 min. at 2000° F. Another containing 2% of silicon was sintered for 45 min. at 2550° F. The density, electrical resistivity, maximum permeability, and hysteresis were measured.—M. A. V.

Internal Friction of Metals and Ferro-Magnetic Alloys. C. Boulanger. (Comptes Rendus, 1947, vol. 224, May 5, pp. 1286–1288). Results are given of a study of the influence of amplitude when using a Coulomb micro-pendulum to measure internal friction of metals and alloys at ordinary temperatures. Ferromagnetic metals and alloys differed from others in that the decrement showed a sharp maximum at a given amplitude.—J. C. R.

Theory of the Anisotropy of Some Magnet Steels Heat-Treated in a Magnetic Field. L. Néel. (Comptes Rendus, 1947, vol. 225, July 16, pp. 109–111).—J. C. R.

Variation of the Coercive Field as a Function of the Density of Sintered Ferromagnetic Powders. L. Weil. (Comptes Rendus, 1947, vol. 225, July 28, pp. 229–230). Iron and ferrocobalt (30% Co) powders, obtained by low-temperature reduction, were used to verify the principle that the coercive field diminishes as the density of the sintered powder increases.—J. C. R.

Developments in Magnetic Steels for Transformers. C. C. Horstman and C. H. Bartlett. (Steel Processing, 1947, vol. 33, Oct., pp. 603–605, 644). Data on the magnetic properties of Hipersil transformer steel are presented and discussed.—R. A. R.

A Test of Operational Weldability. R. Woirin. (Soudure et Techniques Connexes, 1947, vol. 1, Mar.–Apr., pp. 48–55). The author describes and gives the results obtained from a weldability test where a number of local fusions are made on the sheet under examination. The sheets can be classified from the point of view of weldability according to the appearance and diameter of the holes formed. Other factors such as the distance of the tip of the flame from the sheet, the initial temperature, surface condition, and preliminary heat-treatment of the sheet are also examined.—J. C. R.

Flaw Detection by Ultrasonic and Other Non-Destructive Methods. A. C. Rankin. (West of Scotland Iron and Steel Institute, Jan., 1948, Advance Copy). Detailed descriptions, with illustrated examples, are given of ultrasonic, X-ray, and magnetic-powder methods of testing steel for flaws. The scope and economy of the methods, and the statistical presentation of the results are briefly dealt with.—R. A. R.

Use of Ultrasonics in Metallurgy. N. Marinesco. (Centre de Perfectionnement Technique: Chimie et Industrie, 1946, vol. 55, Mar., pp. 180–191). The application of ultrasonics to metallurgy is reviewed with special reference to the control of quality.—R. F. F.

Supersonic Testing of Steel. R. R. Webster. (Yearbook of the American Iron and Steel Institute, 1947, pp. 558–579). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 305.

Ultrasonic Resonance Applied to Non-Destructive Testing. W. S. Erwin and G. M. Rassweiler. (Review of Scientific Instruments, 1947, vol. 18, Oct., pp. 750–753). Ultrasonic vibrations of continuously varying frequency are applied to the part under test which is set into longitudinal vibration at its resonant frequency. The complete range of frequency is traversed during a single travel of the time base of a cathode-ray oscilloscope, and resonance is indicated by a deflection of the spot. The distance of the deflection from the beginning of the time-base gives the frequency. This method is applicable in particular to thickness measurements and flaw detection.—M. A. V.

Transverse Vibrations of Bars and Fatigue Fractures. P. Matthieu. (Engineers' Digest, American Edition, 1947, vol. 4, June, pp. 273–277; July, pp. 330–334). This is an abridged English translation of a paper which appeared in Schweizer Archiv, 1946, vol. 12, Nov., pp. 329–338; Dec., pp. 361–372 (*see* Journ. I. and S.I., 1947, vol. 156, May, p. 140).

The Non-Destructive Testing of Material. J. W. Holleman and W. A. Schultze. (Metalen, 1948, vol. 2, Jan., pp. 93–96). [In Dutch]. The possibilities and limitations of non-destructive methods of testing materials are reviewed. Attempts to find cracks by means of ultra-violet light are discussed and a method is described. —R. A. R.

A 2,000,000 Volt X-Ray Installation. L. Cardenas. (Iron and Steel Engineer, 1947, vol. 24, Dec., pp. 89–99). A 2,000,000-V. X-ray unit installed at the Philadelphia works of the Midvale Co. is described and illustrated. The apparatus provides an ideal non-destructive testing method for certain types of metallurgical products. —J. R.

A New Stereo-X-Ray Apparatus. H. Lüscher. (Archiv für Metallkunde, 1946, vol. 1, Oct., pp. 9–10). In the apparatus described a stereoscopic pair of X-ray generators is actuated respectively by the positive and negative half-cycles of a 50-cycle A.C. supply. The screen is viewed through eyepieces in which the left and right eyes are alternatively obscured by shutters controlled magnetically by the same 50-cycle supply. Persistence of vision gives a stereoscopic effect.—M. A. V.

Microradiography. F. W. Von Batchelder and J. H. Schaum. (Iron Age, 1947, vol. 160, Dec. 11, pp. 94–97). Microradiography is defined as a technique for viewing under magnification images produced on fine-grained photographic films by X-rays passed through very thin metal specimens. The differences between microradiographs and conventional photomicrographs are illustrated.—C. O.

Plastic Replicas for Surface-Finish Measurement. J. Pearson and M. R. Hopkins. (Journal of The Iron and Steel Institute, 1948, vol. 158, Jan., p. 138).

Thermal Conductivity of Metals at High Temperatures. 1. Description of the Apparatus and Measurements on Iron. L. D. Armstrong and T. M. Dauphinee. (Canadian Journal of Research, 1947, vol. 25, Nov., pp. 357–374). An apparatus for measuring the thermal conductivity of metals in the temperature range 0° to 800° C. is described. The method utilizes unidirectional heat flow in a cylindrical sample in a vacuum. The advantages of the method are outlined and a comprehensive analysis of possible errors in the measurements is included. Measurements on Armco irons indicate that results with an absolute error of less than 2% may be obtained. The results of measurements on a sample of Armco iron gave thermal conductivities of 0·1819 c.g.s. units at 0° C. and 0·0698 c.g.s. units at 800° C. A change in slope of the thermal-conductivity/temperature curve was found at a temperature of approximately 375° C., and is tentatively attributed to the presence of 0·03% nickel impurity.

The Creep Properties of Molybdenum, Chromium-Molybdenum, and Molybdenum-Vanadium Steels. J. Glen. (Journal of The Iron and Steel Institute, 1948, vol. 158, Jan., pp. 37–80).

Problems Involved in the Fabrication of High Temperature Alloys. G. Mohling. (Yearbook of the American Iron and Steel Institute, 1947, pp. 519–527). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 305.

Developments in Engineering Materials. J. N. Greenwood. (Commonwealth Engineer, 1947, vol. 35, Sept., pp. 46–48). A brief survey is made of the problems which have arisen with the demand for alloys for use at very high temperatures. The possibility of replacing iron by titanium in such applications is discussed.—C. O.

Heat Resistant Alloy Castings of the "HH" Type. E. F. Wilson. (Alloy Casting Bulletin, 1947, Dec., pp. 1–10). The "HH" alloys are heat-resisting austenitic

alloy steels containing 24–28% of chromium and 11–14% of nickel, for continuous service at 1200° F., or intermittent service up to 2100° F. The conditions under which the alloys are wholly austenitic are discussed, and the effect of temperatures on phase stability and mechanical properties described. Mechanical and physical properties at room and high temperatures are presented in tabular and graphical form. Data are given to illustrate the high resistance to oxidation up to 2200° F. and the effect of flue gases up to 2000° F. Sulphurous flue gases cause interdendritic attack after prolonged exposure at high temperatures. Weldability and machinability correspond to those of other similar austenitic alloys. The pickling and passivating technique is similar to that for 19/9 alloys, and gas carburization, if required, is possible.—M. A. V.

Stability of Steels at Elevated Temperatures. A. B. Wilder and J. D. Tyson. (American Society of Mechanical Engineers: Blast Furnace and Steel Plant, 1947, vol. 35, Feb., pp. 224–225). Short-time and long-time tests on the stability of 60 grades of steel at temperatures of 900°, 1050°, and 1200° F. are being conducted and the results of some of the 1000-hr. tests are reported. Open-hearth carbon steel deoxidized with aluminium, silicon plus aluminium, and titanium plus aluminium graphitized considerably after exposure at 1050° and 1200° F., whilst deoxidized 0·12–0·18% carbon Bessemer steel did not graphitize.—R. A. R.

Graphitization of Steel at Elevated Temperatures. A. B. Wilder and J. D. Tyson. (American Society for Metals, 1947, Preprint No. 14). The stability of 93 different types of steel at 480°, 565°, and 650° C. is being evaluated over a period of 11 years. Welded samples are included in the investigation to evaluate the susceptibility of the steels to graphitization. The results obtained in an examination of 38 examples for evidence of graphite formation after exposure for 10,000 hr. are presented. The effect of deoxidation practice on the tendency of carbon, carbon–molybdenum and carbon–molybdenum–vanadium steels to graphitize is shown. The beneficial effect of chromium on retarding graphitization has been further substantiated. The results for an exposure period of 10,000 hr. indicate that the addition of molybdenum, phosphorus, nickel, and vanadium does not insure freedom from graphite formation in the types of steel investigated.—R. A. R.

Creep and Creep-Rupture Testing. G. V. Smith, W. G. Benz, and R. F. Miller. (American Society for Testing Materials: Steel, 1947, vol. 121, Dec. 8, pp. 88–90, 106–108). A detailed description is given of the equipment used by the United States Steel Corporation for making creep tests. Examples of methods of plotting creep curves are also shown.—R. A. R.

Desulphurization of Iron by Hydrogen. W. Baukloh. (Iron and Steel Institute, 1948, Translation Series, No. 333). This is an English translation of a paper which appeared in Metallwirtschaft, 1936, vol. 15, Dec. 11, pp. 1193–1196. (*See* Journ. I. and S.I., 1937, No. 1, p. 122A).—R. A. R.

Influence of Aluminium Additions and Chemical Composition on the Elasticity of Cast and Wrought Electric-Furnace Mild Steel. P. Bastien and C. Dubois. (Société Française de Métallurgie: Revue de Métallurgie, 1946, vol. 43, Nov.–Dec., pp. 297–306). Samples of acid and basic steels were taken with different additions of aluminium, and tests carried out on cast and wrought specimens, the cast specimens before and after annealing. The influence of chemical composition was also noted.—R. F. F.

Developments in Alloy and Special Steels. C. Sykes. (Metallurgia, 1947, vol. 37, Dec., pp. 75–79) Recent developments in alloy and special steels are discussed with particular reference to gas-turbine applications, overheating, hardenability, machinability, and the relationship between hydrogen and hair-line cracks.—J. R.

Industrial Alloys—III. Tool and Special-Purpose Steels. (Mechanical World, 1947, vol. 122, Dec. 5, pp. 585–589). An account is given of the compositions and characteristics of the common low- and high-alloy steels.—C. O.

Some Properties of Titanium Steels. L. Northcott and D. McLean. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 492–512).

An Evaluation of Boron-Treated Steels. W. F. Toerge. (Steel, 1947, vol. 121, Dec. 8, pp. 93–104). The literature on the effects of boron on the hardenability and other properties of steel is reviewed. The boron-containing agents and methods of adding them, and chemical and spectrographic methods of determining boron in steel are described.—R. A. R.

French Stainless Steels. C. Grenier. (Chimie et Industrie, 1946, vol. 56, Dec., pp. 456–462). French stainless steels are surveyed with special reference to their properties.—R. F. F.

Present Day Special Steels. (Métallurgie, 1947, vol. 79, June, pp. 9, 11). This is a brief account of special steels being produced at the following French steelworks: Société de Denain et d'Anzin; Aciéries du Forez; Compagnie des Forges et Aciéries de la Marine et d'Homecourt; Etablissements Schneider; Aciéries Poldi; Société Stainless.—J. C. R.

The Physics of Sheet Steel. G. C. Richer. (Sheet Metal Industries, 1947, vol. 24, May, pp. 945–952, 962; June, pp. 1147–1154, 1164; July, pp. 1361–1365; Aug., pp. 1572–1580; Sept., pp. 1783–1785; Oct., pp. 1990–1992; Nov., pp. 2194–2198, 2206; Dec., pp. 2411–2416). An attempt is made to outline the general nature of the impact of modern physics on problems relevant to the production and use of sheet steel, particularly the qualities used for deep-drawing and electrical-engineering purposes.

Mechanism of Fracture of Glass and Similar Brittle Solids. N. W. Taylor. (Journal of Applied Physics, 1947, vol. 18, Nov., pp. 943–955). A theory is proposed which connects the stress f, required to break a brittle material in simple tension, with its duration of application t. The slow process preceding fracture is shown to be the orientation of the atomic network contained in an elementary prism of length $r = \lambda_0 E/f$ where E is Young's modulus and λ_0 is the critical elongation required for fracture. The rate-controlling factor is the activation energy, $E\alpha/f$, for the orientation or rearrangement of the atomic network under the stress f. Moisture on glass, and moisture plus oxygen on certain metals, are important catalytic or fatigue-promoting factors because they reduce the unit activation energy α.—R. A. R.

Examination of a Pit Cage Pivot. (Prévention des Accidents et Contrôles Techniques, 1948, vol. 2, Feb., pp. 61–62). An account is given of a metallographic examination and mechanical tests on a pit cage pivot which failed in service. The factors which caused the failure are analysed; faulty methods of fabrication were considered the main causes.—J. C. R.

X-Ray Testing and Progress in the Foundry. H. Reiniger. (Archiv für Metallkunde, 1947, vol. 1, Oct., pp. 37–38). Examples are given of the use of X-ray tests in foundries for determination of the structure of cast metals, and detection of faults.—M. A. V.

A Study of the Metallurgical Characteristics of Three Induction-Hardened Steels Heated at Various Rates. J. W. Poynter. (American Society for Metals, 1947,

Preprint No. 6). Specimens of 0·46% and 1·06% carbon steels and two nickel–chromium–molybdenum steels prepared in the pearlitic, normalized, and spheroidized conditions were induction-heated at various rates to a temperature slightly above the critical, and to 1040° C. Microhardness determinations and metallographic examinations on the hardened zone were made. The hardness was found to increase with heating time until sufficient carbon to produce full hardness had been dissolved; the hardness then decreased slightly with longer heating times. This decrease is attributed to the presence of more retained austenite in the structure caused by quenching a more homogeneous austenite. —R. A. R.

The Dimensional Stability of Steel. Part II—Further Experiments on Subatmospheric Transformations. S. G. Fletcher, B. L. Averbach and M. Cohen. (American Society of Metals, 1947, Preprint No. 7). The transformation of retained austenite by subzero cooling has been investigated in three typical tool steels, and the stabilization of this austenite toward subzero transformation has been studied as a function of austenitizing and tempering treatments. It is shown that, if the amount of retained austenite is low, virtually all of it can be transformed by immediate refrigeration after quenching. However, if the amount of retained austenite is high, only a fraction of it can be transformed by refrigeration. Almost complete stabilization in either case may be obtained by tempering before sub-cooling.—R. A. R.

The Dimensional Stability of Steel. Part III—Decomposition of Martensite and Austenite at Room Temperature. B. L. Averbach, M. Cohen and S. G. Fletcher. (American Society for Metals, 1947, Preprint No. 8). The decomposition of martensite and retained austenite at room temperature has been measured in a plain carbon tool steel and a ball-bearing steel by observing the dimensional changes which occur in hardened specimens as they age at room temperature. Tempering hastens the initial shrinkage, but the subsequent contraction at room temperature proceeds as though the initial contraction had occurred at room temperature. An equation has been fitted to the basic reaction curve so that it is possible to predict the dimensional behaviour of martensite after a given tempering treatment. Retained austenite decomposes isothermally at room temperature to cause an increase in length. Tempering decomposes some austenite, but the reaction is not additive, because of a stabilizing effect which also occurs during the tempering treatment.—R. A. R.

Acicular Transformations in Alloy Steel. E. A. Loria. (American Society for Metals, 1947, Preprint No. 9). Data of a fundamental nature have been obtained regarding the acicular structure occurring within the intermediate isothermal transformation range of a nickel–chromium–molybdenum and a chromium–molybdenum steel containing appreciable amounts of a number of carbide-forming elements, sufficient to make one of them slightly hypereutectoid below the upper nose of its time-temperature-transformation diagram. The acicular transformation in this steel is unique in that the primary carbon-rich plate constituent first forms by a lattice shearing process and then undergoes a slow but complete change in structure after long holding periods at temperature.—R. A. R.

What Do We Know About Rolled Threads? W. A. Hawkins. (Machinist, 1948, vol. 91, Jan. 3, pp. 1207–1213). A summary is made of the results of research work carried out in Switzerland and Great Britain on the metallography and physical properties of rolled threads in steel.—C. O.

Comparing Plastics. C. E. Staff, J. M. Hill, jun., and H. M. Quackenbos, jun. (Machine Design, 1947, vol. 19, July, pp. 112–116). Data are given to show how the mechanical properties of thermosetting, thermoplastic, and laminated plastics compare with those of steel and aluminium.—C. O.

How Processing Affects Bolt Fatigue Strength. N. B. Green. (Machine Design, 1947, vol. 19, Dec., pp. 138–140). An investigation of the effects of the method of manufacture of the heads and threads of steel bolts for aircraft on their fatigue strength is reported. Bolts with heads and threads cold-rolled after heat-treatment were found to have fatigue lives four to ten times greater than bolts made in other ways.—C. O.

The Nature and Effect of Porosity in Electrodeposits. W. A. Wesley. (33rd Annual Technical Sessions of the American Electroplaters' Society, 1946, June, pp. 211–213). A summary is made of the plans for an experimental investigation of the nature and effect of porosity in electrodeposits being undertaken by a Committee of the American Electroplaters' Society.—C. O.

Methods for Testing Adhesion of Electrodeposits. A. L. Ferguson. (33rd Annual Technical Sessions of the American Electroplaters' Society, 1946, June, pp. 188–195). A summary is made of conclusions reached by a Committee of the American Electroplaters' Society studying methods for testing the adhesion of electrodeposits on metallic surfaces. It is considered that no test closely approaching the ideal is at present in existence.—C. O.

The Mechanical Properties of a Nickel–Chromium–Molybdenum Steel Obtained by Stepped Quenching. G. Delbart and R. Potaszkin. (Journal of The Iron and Steel Institute, 1947, vol. 157, Dec., pp. 527–535).

Metallurgical Properties of High Yield Strength Seamless Line Pipe. A. B. Wilder and J. D. Dyson. (Welding Journal, 1947, vol. 26, Oct., pp. 872–880). An investigation of the welding properties of seamless tubing, 26-in. in outside dia., and 0·303 in. in wall thickness, made from a steel containing 0·40% max. of carbon and 1·40% max. of manganese, with a minimum yield strength of 52,000 lb./sq. in., is reported.—C. O.

Physical Properties of Steels for Tubular Products. A. B. Wilder. (American Society for Testing Materials: Steel, 1947, vol. 121, Sept. 29, pp. 102–112). The results of an investigation of the structure, and tensile and impact properties of Bessemer, open-hearth, and electric furnace steels used in the manufacture of tubes are presented.—C. O.

Mechanical Properties of Metals at Low Temperatures—A Survey. L. Seigle and R. M. Brick. (American Society for Metals, 1947, Preprint No. 19). The literature on the mechanical properties of metals at subatmospheric temperatures is reviewed. The bibliography contains 95 references.—R. A. R.

The Fatigue Strength of Binary Ferrites. E. Epremian and E. F. Nippes. (American Society for Metals, 1947, Preprint No. 21). An investigation has been made of the specific strengthening effect of alloying elements in binary solid solution on the endurance limit of ferrite. Results of tests on samples in the Quinlan pneumatic fatigue machine indicate that the relative order of effectiveness is: titanium, molybdenum, silicon, manganese, nickel, cobalt, and chromium. The effectiveness of these elements varies inversely with the extent of their solid solubility in iron. Observations of the change in the power requirements to maintain a bar at constant stress during the progress of a fatigue test are associated with changes in the damping capacity due to cold work. —R. A. R.

The Bend Test for Hardened High Speed Steel. A. H. Grobe and G. A. Roberts. (American Society for Metals, 1947, Preprint No. 22). The object of this investigation was to develop the bend test as a useful tool for measuring the toughness of tool steels, and to apply this test to high-speed steels. In the development of the test, three factors were investigated, namely, the specimen size, single- and double-point loading, and the number of specimens necessary to obtain reasonably accurate values of yield strength, bend strength, plastic deflection, and total deflection.—R. A. R.

Effects of Grinding on Physical Properties of Hardened Steel Parts. H. E. Boyer. (American Society for Metals, 1947, Preprint No. 23). An intensive study has been made of the unbalanced residual stresses induced by grinding on highly hardened steel parts, and the ultimate effect of such stresses upon the physical properties. Hardened S.A.E. 52100 steel (a medium-chromium steel) was used exclusively as the material for study though it is indicated that the findings may be applied to other steels of the deep-hardening type. The results established the fact that fatigue and other physical properties are seriously affected by incorrect planning of grinding operations.—R. A. R.

Recrystallization as a Measurement of Relative Shot Peening Intensities. K. B. Valentine. (American Society for Metals, 1947, Preprint No. 24). The phenomena of recrystallization and grain growth of a critically strained, low carbon steel at subcritical temperatures were used as a means of determining the depth to which the cold work introduced by shot-peening penetrated. Data from tests utilizing this method indicate that depth of penetration is increased by (*a*) increase of shot size; (*b*) increase of shot velocity; and (*c*) increase of time of peening. Penetration depths up to 0·025 in. were observed.—R. A. R.

Macrosegregation in Some Alloy Steel Ingots. J. W. Spretnak. (American Society for Metals, 1947, Preprint No. 25). The macrosegregation in six alloy steel ingots was examined, using the published allowable errors in the analysis of steel as the criterion in establishing the occurrence of segregation. A considerable variation in the amounts of segregation was found among the six ingots.—R. A. R.

The Distribution of Oxygen and Nitrogen in an Alloy Steel Ingot. C. F. Sawyer, J. W. Spretnak and G. Derge. (American Society for Metals, 1947, Preprint No. 26). The distribution of oxygen and nitrogen in a 26 × 26 in. ingot of S.A.E. 4335 steel was studied by means of the vacuum-fusion method of analysis. Groups of ten adjoining 12-g. samples from ten positions in the ingot were analysed. The average oxygen content of the groups of samples from the centre position near the extreme bottom of the ingot was significantly higher than the average for the other nine positions. There was no significant difference in the average nitrogen content of any of the ten ingot positions studied.—R. A. R.

The Effect of Silicon on the Properties of Cast Carbon and Carbon-Molybdenum Steels. N. A. Ziegler, W. L. Meinhart, and J. R. Goldsmith. (American Society for Metals, 1947, Preprint No. 29). The effect of silicon on thermal characteristics, microstructures, physical properties and weldability of plain carbon and carbon-molybdenum cast steels of three different carbon contents (0·1% max., 0·15%, and 0·30%) has been investigated. Increasing the silicon content from 0·3% to 2% produces: (*a*) Moderate increase of tensile strength, yield point, and hardness; (*b*) moderate decrease of elongation and reduction of area; and (*c*) a considerable reduction of impact resistance.—R. A. R.

CORROSION

Corrosion-Resisting Metals and Alloys. H. J. Butterill. (Canadian Mining and Metallurgical Bulletin, 1947, Nov., pp. 521–526). The electrochemical theory of corrosion is briefly outlined and the corrosion-resistant properties of several classes of alloy steels, with special reference to their use in mining equipment are discussed.—R. A. R.

Contribution to the Study of the Rôle of Temperature in the Corrosion of Iron in an Aerated Salt Solution. R. Reiller. (Métaux, Corrosion, Usure, 1942, vol. 17, May, pp. 69–73). The influence of temperature upon the corrosion of iron in salt solutions was studied using an Evans cell. The rate of corrosion increased rapidly up to a temperature of 45° C. reaching a maximum at about 50° C.—J. C. R.

Problems in Cathodic Protection. F. E. Dolson. (Journal of the American Waterworks Association, 1947, vol. 39, Nov., pp. 1079–1089). The economic importance of cast-iron pipe-line corrosion is discussed, and the theory of corrosion and of cathodic protection is outlined. The question of interference is considered in particular, and the consequent need for co-operation between different authorities explained. An appendix outlines a proposed organizational scheme for cathodic protection committees.—M. A. V.

Electrical Instruments and Measurements in Cathodic Protection. J. M. Pearson. (Corrosion, 1947, vol. 3, Nov., pp. 549–566). Several instruments based on the D'Arsonval movement, and electronic instruments for measurements in connection with cathodic protection against corrosion are described and the circuit diagrams are given.—R. A. R.

Cathodic Protection of Hot Water Tanks. J. M. Bialosky. (Corrosion, 1947, vol. 3, Nov., pp. 585–591). The theory of cathodic protection is outlined and its application to prevent the corrosion of hot-water tanks is discussed.—R. A. R.

Location and Selection of Anode Systems for Cathodic Protection Units. D. B. Good. (Corrosion, 1947, vol. 3, Nov., pp. 539–548). In the cathodic protection of underground pipelines it is necessary to exercise great care in selecting the positions of the anodes. Means of determining soil resistance are described and other factors determining the anode shape and position are discussed.—R. A. R.

Concept of the Hydrogen Potential in Steam-Metal Reactions. C. A. Zapffe. (American Society for Metals, 1947, Preprint No. 15). A thermodynamic study of numerous reactions of metal and alloys with moisture develops the concept of the "hydrogen potential"—a chemical attribute of the hydrogen released during the moment of reaction, which generates known or calculable pressures of hydrogen in a closed system; this attribute can therefore in turn be measured for dynamic systems in terms of those pressures. Since the absorption of hydrogen by metals is a function of the hydrogen pressure, these hydrogen potentials provide a basis for calculating the liability of the various metal systems to hydrogen pick-up from the moisture reaction. Calculations for iron, steel, stainless steel, nickel, chromium, manganese, silicon, aluminium, and magnesium are presented in the form of graphs, and the significance of the plots is discussed.—R. A. R.

Corrosion Inhibitors. A. G. Sussex. (Australian Institute of Metals, Symposium on Recent Advances in Physical Metallurgy: Australasian Engineer, 1947, Nov. 7, pp. 68–75). A short review is made of the literature on the theory and experimental study of corrosion

inhibitors, and recent work on chromates, soluble oils, acid pickling, and stress-corrosion inhibition is noted. —C. O.

Mechanism of Corrosion of Iron by Water as a Function of *p*H Rôle of Dissolved Oxygen. Degasification by Heating, Vacuum or Chemical Means. C. Cabanes. (Chaleur et Industrie, 1946, vol. 27, Nov., pp. 261–270). The mechanism of corrosion of iron by water and the part played by dissolved oxygen are discussed. Condensers and other means of removing dissolved gas are described.—J. C. R.

Resistance of Sensitized Stainless Steels to Boiling Nitric Acid. R. S. Stewart. (Metal Progress, 1947, vol. 52, Dec., pp. 971–973). Data are given to show that the use of the Huey test—boiling in 65% HNO_3 for five 48-hr. periods and determining the loss in weight—for the evaluation of the general corrosion resistance of titanium-stabilized 18/10 stainless steel subjected to a "sensitizing" heat-treatment is unwarranted.—C. O.

Corrosion Studies in Natural Gas Condensate Wells. D. A. Shock and N. Hackerman. (Industrial and Engineering Chemistry, 1947, vol. 39, Oct., pp. 1283–1286). A mechanism is proposed to explain the absence of localized attack and the low rate of general attack in a certain type of natural gas condensate well.—R. A. R.

Protective Film Formation on Stainless Steels. W. H. Colner. (Journal of Corrosion, 1947, vol. 4, Nov.–Dec., pp. 11–21). Methods of studying oxide films on iron, chromium, nickel, and their alloys are described, and theories for the protection afforded by films and the laws of film growth are discussed.—A bibliography of 80 references is appended.—R. A. R.

Some Factors Affecting the Corrosion of Packaged Metal Parts. C. G. Lavers, A. H. Woodcock, and J. A. Pearce. (Corrosion and Materials Protection, 1947, vol. 4, Nov.–Dec., pp. 6–10). Tests are described which demonstrated the relative merits of different ways of wrapping and packaging bearings and metal parts to resistant corrosion when stored in tropical climates. —R. A. R.

Surface Studies of Metals from the Corrosion Standpoint. M. G. Fontana. (Corrosion, 1947, vol. 3, Nov., pp. 567–579). This paper is a progress report on research on the formation of surface films on 18/8 stainless steel at normal and elevated temperatures, which was sponsored by the Office of Naval Research. The investigations have already been reported by the authors and F. H. Beck (*see* Journ. I. and S.I., 1947, vol. 157, Oct., p. 316).—R. A. R.

Glossary of Terms Used in Corrosion. (Transactions of the Electrochemical Society, 1947, vol. 90, pp. 585–591). This glossary of corrosion terms was prepared for inclusion in the forthcoming *Corrosion Handbook*, sponsored by the Electrochemical Society. It was produced jointly by the Editorial Advisory Board of the *Corrosion Handbook* and Sub-committee V of the American Co-ordinating Committee on Corrosion.—R. A. R.

ANALYSIS

Microdetermination of Carbon in Ferrous Products. A. Lassieur. (Revue de Métallurgie, 1941, vol. 38, Feb., pp. 50–54). An apparatus for the determination of carbon, in minute samples of steels, is described. Oxygen is passed over the sample in an electrically heated combustion chamber, and the gases formed are passed through baryta water, which is then titrated against an acid potassium phthalate solution of 0·750 g. per litre.—R. F. F.

Contribution to the Problem of Dissolved Gases in Metallurgical Products. G. Chaudron. (Métaux, Corrosion, Usure, 1942, vol. 17, July, pp. 113–123). The methods employed for the determination of hydrogen in a metal by chemical analysis by heating in a vacuum and by the Chaudron-Moreau method of ionic-bombardment are outlined. The work of various investigators on the ways in which hydrogen is absorbed by metals, its solubility and effect on the structure and mechanical properties of metals is reviewed and discussed.—J. C. R.

A Systematic Scheme for Identifying Corrosion Resistant Metals. C. J. Zeeh. (Metal Progress, 1947, vol. 52, Nov., pp. 824, 824-B, 825). A scheme for the rapid identification of corrosion-resistant metals, making use of the electrograph, is outlined.—C. O.

Spectrographic Determination of Small Amounts of Aluminium in Ordinary and Special Steels. R. Castro. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 5th Congress, 22–24 Jan., 1946, pp. 17–36). Results obtained at the laboratory of the Ugine Steelworks are described. A Zeiss Qu 24 spectrograph was used and the choice of lines for aluminium and iron is discussed. These results show a maximum average error of $\pm 0.0006\%$ for amounts of aluminium between 0·004% and 0·025%, and the average error is in the region $\pm 2{\cdot}5$–5% of the aluminium content of the specimen when this is between 0·025% and 0·150%—R. F. F.

Notes on Spectrographs. H. Tardy. (Groupement pour l'Avancement des Méthodes d'Analyses Spectrographique des Produits Métallurgiques, 5th Congress, 22–24 Jan., 1946, pp. 37–45). The principles and construction of spectrographs are discussed.—R. F. F.

Comparison of the Luminosities of the Zeiss Qu 24 Spectrograph and the Jobin and Yvon Zelande Spectrograph. E. Lœuille. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 5th Congress, 22–24 Jan., 1946, pp. 46–68). The luminosity of the above spectrographs is compared and the influence of luminosity on working curves is studied.—R. F. F.

Instantaneous Spectrography. J. Orsag. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 7th Congress, 21–23 Jan., 1947, pp. 57–59). Modifications carried out on a spectrograph in order to allow rapid determination with the naked eye, or in the case of ultra-violet lines, with a photocell and potentiometer, are discussed.—R. F. F.

"Applied Research Laboratories" (A.R.L.) Linear Spectrographs. E. Dussourd. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrogaphique des Produits Métallurgiques, 7th Congress, 21–23 Jan., 1947, pp. 71–78). The characteristics of the A.R.L. spectrograph are compared with those of a prismatic spectrograph of the "Grand Littrow-Quartz" type. The principles and operation of A.R.L. spectrographs are discussed.—R. F. F.

Report on Tests on Durr's Spark Generator. R. Castro. (Groupement pour l'Avancement des Méthodes d'Analyses Spectrographique des Produits Métallurgiques, 7th Congress, 21–23 Jan., 1947, pp. 79–87). The Durr spark generator is described and compared with the Feussner generator for luminosity, electrical characteristics, shape, stability of discharge, and accuracy of determination.—R. F. F.

The Application of Rapid Analytical Processes in Industrial Laboratories. H. Moritz. (Archiv für Metallkunde, 1947, vol. 1, Mar., pp. 97–101). The accuracies and merits of spectrographic, polarographic, colorimetric,

and potentiometric methods of analysis are discussed and compared, and their application under present conditions in Germany is considered.—R. A. R.

The Fundamentals and Present Position in the Development of Spectrochemical Equipment and Processes. H. Moritz. (Archiv für Metallkunde, 1947, vol. 1, Mar., pp. 102–108).

Spectrochemical Analysis in the Process Laboratories of the Iron and Steel Industry. H. Moritz. (Archiv für Metallkunde, 1947, vol. 1, Mar., pp. 115–121). The state of development of spectrographic analysis in American steelworks laboratories is reviewed and compared with the position of this method of analysis in Germany. —R. A. R.

Spectrochemical Semi-Quantitative Analysis. H. Moritz. (Archiv für Metallkunde, 1947, vol. 1, Mar., pp. 122–123). The application of the spectrograph for rapid semi-quantitative analysis is described with three examples.—R. A. R.

A Method for Micro-Spectrography of Metals. F. R. Bryan and G. A. Nahstoll. (Journal of the Optical Society of America, 1947, vol. 37, May, pp. 311–316). A method is described for making qualitative spectrographic analyses of areas of metal less than 0·05 mm. in dia. The apparatus consists of a holder for the counter electrode and the specimen, an electronic spark generator, and a medium quartz spectrograph.—R. A. R.

The Spectrographic Analysis of Ferro-Silicon. J. H. Coulliette. (Journal of the Optical Society of America, 1947, vol. 37, Aug., pp. 609–613). A method for the spectrographic analysis of materials consisting of two or more principal components is described and full details of its application to the analysis of ferrosilicon are given.—R. A. R.

Spectrophotometric Determination of Iron in Ores with 2,2′-Bipyridyl. J. P. Mehlig and M. J. Shepherd, jun. (Chemist Analyst, 1947, vol. 36, Nov., pp. 52–55). A spectrophotometric method for the determination of iron in ores is outlined. The method depends upon reducing the iron with hydroxylamine hydrochloride and measuring the light transmittancy at 522μ of the coloured solutions produced by 2,2′-bipyridyl with the pH range 3–9. The results obtained agree closely with those given by the dichromate titration method, and show that ores containing up to 58% of iron can be estimated in this way.—C. O.

A Rapid Electrolytic Method for the Determination of Silica Inclusions in Steel. A. Skapski, A. Bielanski, and M. Sobieski. (Revue de Métallurgie, 1946, vol. 43, July–Aug., pp. 229–233). This is a translation of an article which appeared in the Polish journal Hutnik, (1938, vol. 10, p. 470). To increase the speed of the electrolytic determination of inclusions an electrolyte of composition 10 g. sodium chloride, 100 g. potassium bromide, and 30 g. sodium citrate per litre was used and a silk cloth replaced the normal cellophane bag to collect the inclusions. Results obtained by this method are within about 0·002% of those obtained by the bromide method.—R. F. F.

Possibilities of Colorimetry for the Analysis of Metallic Alloys. P. Michel. (Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 7th Congress, 21–23 Jan, 1947, pp. 101–112). Colorimetry is studied mathematically and factors influencing results noted. The various operating methods are compared and photo-electric colorimeters discussed. —R. F. F.

Investigations on Colorimetric Methods of Metallurgical Analysis—Permanent Standards for the Colorimetric Determination of Molybdenum in Alloy Steels. G. V. L. N. Murty. (Metallurgia, 1947, vol. 36, Oct., pp. 345–346). An investigation of the use of mixtures of potassium dichromate and cobalt nitrate solutions as standards for the colorimetric determination of molybdenum is described. It was found possible to prepare satisfactory duplicates which remained stable for more than a month, for the whole range of alloy steels.—C. O.

The Direct Colorimetric Determination of Tungsten in Cast Iron. W. Westwood and A. Mayer. (Analyst, 1947, vol. 72, Nov., pp. 464–469). A colorimetric method is suggested for the determination of small amounts of tungsten in cast iron. It is based upon the formation of an intense yellow tungsten thiocyanate complex in strong hydrochloric acid solution in the presence of stannous chloride.—C. O.

Determination of Maximum Inherent Moisture in Coal by Controlled Vaporization of Adherent Moisture. J. A. Dulhunty. (Journal and Proceedings of the Royal Society of New South Wales, 1947, vol. 81, Part I, pp. 60–68). The problem of determining the maximum inherent moisture, *i.e.*, the moisture which coal contains when all the capillary spaces are filled with absorbed moisture, but no adherent moisture is present, is discussed. A method is suggested based on the fact that capillary-held moisture has a sub-normal vapour pressure, while adherent moisture has a normal vapour pressure. Adherent moisture is vaporized from wet coal by heating at constant temperature in an atmosphere of water vapour at a pressure just low enough to allow vaporization. The inherent water remaining can be determined by drying at 105° C. in the usual way.—C. O.

How to Measure and Determine the Chemical Composition of Gases Escaping from Oil-Bonded Cores During the Cast. V. Voleník. (Hutnické Listy, 1946, vol. 1, No. 2, pp. 25–31). [In Czech].

The Determination of Columbium in Rustless and Heat-Resisting Steels. Part I. B. Bagshawe and W. T. Elwell. (Journal of the Society of Chemical Industry, 1947, vol. 66, Nov., pp. 398–400). A procedure is described for the determination of columbium in rustless and heat-resisting high chromium–nickel steel. Provision is made for the presence of tungsten, titanium, and molybdenum. By a slight adjustment of conditions, tungsten precipitation is quantitative and a simultaneous determination may be made. The efficiency of hydrolysis separations is discussed and a method of sulphurous acid hydrolysis from divalent iron solution is recommended.—R. A. R.

The Determination of Columbium in Rustless and Heat-Resisting Steels. Part II. A Co-operative Examination of Some of the Methods Available. S. W. Craven. (Journal of the Society of Chemical Industry, 1947, vol. 66, Nov., pp. 400–407). Results are given of a co-operative examination of several methods of determining columbium in 18/8 chromium–nickel steels by six laboratories. Various features of the methods are discussed and the order of agreement obtained by different laboratories working independently is shown.—R. A. R.

Semi-Quantitative Spot-Test Analysis of 18/8 Cr–Ni Steels. A. Claeys and J. Gillis. (Royal Academy of Sciences of Belgium: Analytica Chimica Acta, 1947, vol. 1, Nov., pp. 364–370). A method for making semi-quantitative analyses of steels high in chromium and nickel is described in which the surface of the specimen is attacked by a few drops of *aqua regia* and a series of diluted solutions is prepared to establish the concentration limit, *i.e.*, the dilution at which there ceases to be a reaction. Once a percentage/concentration-limit curve has been set up, standard steels need not be used for comparison. The method covers the determination of nickel, chromium, molybdenum, manganese, and titanium.—R. A. R.

Contribution to the Determination of Manganese and Chromium in Steel and Alloys. L. Nigaud. (Chimie et Industrie, 1946, vol. 56, Oct., pp. 287–291). A description is given of an accurate and rapid volumetric method for the simultaneous determination of manganese and chromium. It is an adaption of Travers' method of oxidation of manganese and chromium by ammonium persulphate in the presence of silver nitrate.—R. F. F.

Spot Test for the Detection of Cadmium in Plating on Metals. K. A. Jorczak. (Chemist Analyst, 1947, vol. 36, Nov., p. 62). A brief note is made of a drop test using hydrochloric acid and sodium sulphide for the detection of cadmium in zinc plating.—C. O.

Determination of Impurities in Electroplating Solutions. E. J. Serfass. (33rd Annual Technical Sessions of the American Electroplaters' Society, 1946, June, pp. 181–188). A brief account is given of work in progress on the development of methods for the analysis of electroplating solutions for metallic impurities. Schemes are outlined for the colorimetric determination of lead, iron, manganese, cadmium, and chromium, and for the gravimetric determination of silicon.—C. O.

The Quantitative Chemical Determination of the Structure of Annealed Chromium Steels on the Basis of Residue Analyses. T. Heczko. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1947, vol. 92, July–Sept., pp. 125–139). Methods are described for determining the carbides present in chromium steels and the proportions of chromium in the carbides and the matrix. The methods are based on the analysis of the carbide residues after dissolving the metal in bromine water.—R. A. R.

Electrographic Methods of Analysis. E. A. Arnold. (Transactions of the Electrochemical Society, 1947, vol. 90, pp. 229–234). Examples of electrographic methods of analysis are cited. In this technique the specimen is made an anode in a circuit against an inert cathode, the electrolyte and necessary reagents being soaked into filter paper in intimate contact with both anode and cathode. As the current flows the metals of the anode enter the paper and react with the reagents in it to form insoluble compounds. These compounds may be coloured, or may be made to react with suitable reagents by a process similar to photographic development to give distinctly coloured compounds. The colour intensity of the stain on the paper is proportional to the period of current flow and to the percentage of the metallic ion present in the sample.

The time required is less than for the conventional type of analysis, and the amount of metal consumed is of the order of microgrammes rather than milligrammes.—R. A. R.

BOOK NOTICES

EASTMAN KODAK CO. "*Radiography in Modern Industry.*" La. 8vo, pp. 122. Illustrated. Rochester, N.Y., 1947 : Eastman Kodak Co. X-Ray Division. (Price 18*s.* 6*d.*).

This book is intended to provide a dependable text of the fundamental knowledge necessary for efficient radiographic practice. Care has been taken in arranging its contents to meet the need of the serious professional worker as well as the student reader. It consists of the following chapters : Radiography's Function in Industry ; The Radiographic Process ; X-Ray Generating Apparatus ; Geometric Principles ; Factors Governing Exposure, Radiographic Screens, Scattered Radiation ; Arithmetic of Exposure, Sensitivity and Detail Visibility ; Special Technics ; Kodak Industrial X-Ray Films ; Processing ; The Processing Room. Appendix I : Sensitometric Characteristics ; II : Protection ; III : Unsatisfactory Radiographs. A bibliography of the literature is included.

BRITISH INTELLIGENCE OBJECTIVES SUBCOMMITTEE. B.I.O.S. Overall Report No. 1. "*Report on the Petroleum and Synthetic Oil Industry of Germany.*" Fol., pp. 134. Illustrated. London, 1947 : H.M. Stationery Office. (Price 10*s.*).

This is the first of a new series of BIOS reports which has as its object the final assessment of results of the whole of the previous BIOS reports. The Overall Reports are surveys of the individual industries investigated in Germany and present not only summaries of the BIOS, CIOS, FIAT, and JIOA reports, but attempt to be at the same time critical appraisals of their subjects. They have been compiled with the object of comparing the state of development of British and German industries—thus providing a permanent reference to the outstanding German achievements. At the same time they will show where British industry is ahead of German technology and where we cannot learn anything from Germany. The present report has been prepared by a special committee of the Ministry of Fuel and Power and deals extensively with three specialized fields, namely carbonization (gas engineering), hydrogenation and Fischer-Tropsch synthesis (chemical engineering), and crude oil production and petroleum refining (petroleum engineering). Each section has been written by persons engaged in the appropriate field, and a glossary is included of technical terms and abbreviations.—R. E.

SIMONS, E. N. "*Steel Files. Their Manufacture and Application.*" 8vo, pp. ix + 136. Illustrated. London, 1947 : Sir Isaac Pitman and Sons, Ltd. (Price 15*s.* 0*d.*).

This may be regarded as a companion volume to the author's earlier work on saws and sawing machinery, and it does for the humble but indispensable file what the previous book did for saws. It may surprise many that anyone could write a book solely on files, and secondly that the subject was worth the trouble. A study of this volume leaves the reader in no doubt as to the author's ability, and the worthiness of the subject. The author's full treatment of his matter is exemplified by the inclusion of chapters on the history and manufacture of files, the types and qualities of files, methods of testing and factors controlling efficiency, and a valuable chapter on the art of filing. His long association with the Sheffield file-making industry shows itself in the well informed style in which the book is written, and the somewhat narrow subject is thereby invested with an interest

Abstracts

A limited quantity of reprints of the Abstract Section printed on one side only is available. Copies from January 1948, can be obtained at a cost of £2 per annum on application to the Secretary.

which carries the reader comfortably along. It may truly be said that Mr. Simons has justified his choice of subject, and in the light of his work the ordinary file assumes its proper status as a unique tool, fashioned by craftsmen, and perfected by evolution.

The book is well illustrated with line drawings and photographs which complement the text admirably, and the only criticism of an excellent treatise is that an occasional looseness of description halts the reader momentarily and detracts somewhat from the general level of competence.

It would be unfair to Mr. Simons to conclude this review without mention of his rather remarkable and outspoken final chapter on the future of the file industry. Much of what he writes has been heard in the last twenty years from the mouths of politicians and industrialists, but from Mr. Simons' pen it does not bear the stamp of the cliché or catch phrase. He writes with evident sincerity and full knowledge, and his conclusions are not palatable. Even if one is not interested in files this chapter on the needs of the file-making industry must raise reflections of a wide and, especially at the present time, an unmistakable national importance.

S. L. ROBERTON

"*Werkstoff-Handbuch Stahl und Eisen.*" Herausgegeben vom Verein deutscher Eisenhüttenleute. Berichtigter Nachdruck 1944 der 2. vollständig bearbeiteten Auflage 1937. 8vo. Düsseldorf-Pössneck, 1944: Verlag Stahleisen m.b.H.

Although this is described as "a corrected re-print made in 1944 of the second complete revised edition of 1937" the sole difference appears to be the addition of some 15% of papers bearing the date August, 1940; the remainder is of the date November, 1937.

Completed under the editorship of Dr.-Ing. Otto Petersen, Professor Dr.-Ing. E. H. Schulz, and Dr.-Ing. Karl Daeves, the volume consists of a series of brief monographs under five main headings. (*a*) General: This covers the physical properties of iron, the German equivalents of British measures, and the weight of simple sections, etc. (*b*) Properties and Tests: This deals with the magnetic, electrical, thermal, elastic, fatigue, and impact properties of iron and steel, and with methods for determining corrosion resistance, weldability, hardenability and machinability. (*c*) Varieties of iron and steel classified according to manufacture and composition: This deals with the effect of alloying elements on steel, and treats of a number of alloy steels. (*d*) Varieties of iron and steel for specific purposes: This section covers a great variety of special steels, *e.g.*, high-tensile structural steels, magnet steels, non-rusting and heat-resisting steels, steels for cutting tools, files, cables, rails, and free-machining steels. (*e*) Steel working and testing: Here are treated the hot- and cold-working and heat-treatment of steels, pickling and surface protection, analysis, metallography, and non-destructive testing. The work is illustrated with numerous graphs and diagrams.—J. P. S.

TREVETHICK, R. A. "*Advanced Industrial First-Aid*, 1947." Sm. 8vo, pp. 63. Rotherham: Henry Garnett and Co., Ltd. (Price 3*s.* 0*d.*).

In this small monograph, the author, who is the Medical Officer to Steel, Peech and Tozer, Ltd., a Branch of the United Steel Companies, Ltd., gives up-to-date recommendations on first-aid in industry. Although written primarily for the above-mentioned works it is hoped it may eventually have a wider circulation. Each chapter deals with a major problem and its treatment in 1947.—R. E.

NEW PUBLICATIONS

BALLARD, W. E. "*Metal Spraying and Sprayed Metal.*" Third Edition based on previous editions by E. C. Rollason and by T. Henry Turner and N. F. Budgen. 8vo, pp. xvi + 362. Illustrated. London, 1948: Charles Griffin and Co., Ltd. (Price 32*s.*).

BRITISH STANDARDS INSTITUTION. B.S. 146: 1947. "*Portland Blastfurnace Cement.*" 8vo, pp. 31. London, 1947: The Institution. (Price 3*s.* 6*d.*).

BRITISH STANDARDS INSTITUTION. B.S. 1429: 1948. "*Annealed Steel Wire for Oil-Hardened Tempered Springs.*" 8vo, pp. 10. London, 1948: The Institution. (Price 2*s.*).

CHRISTEN H. "*Werkstoffbegriffe.*" Eine Erläuterung werkstofftechnischer Begriffe zum Gebrauche an technischen Mittelschulen und zum Selbststudium. Dritte Auflage. Frauenfeld, 1947: Verlag von Huber & Co.

COPP, D. "*Power and Process Steam Engineering.*" 8vo, pp. 173. Illustrated. London: Edward Arnold and Co. (Price 15*s.*).

DU RIETZ, D., und H. KOCH. "*Praktisches Handbuch der Lichtbogenschweissung.*" 8vo, pp. viii + 300. 2. Aufl. Braunschweig, 1947: Vieweg und Sohn. (Price 15.00 R.M.).

Foundryman's Compendium. Birmingham: Foundry Services, Ltd. (Price 7*s.* 6*d.*).

FRANCIS W. "*Boiler House and Power Station Chemistry.*" Second Edition, 8vo, pp. xiv + 274. Illustrated. London: Edward Arnold and Co. (Price 21*s.* net).

GAZZI, V. "*Spectroscopy Applied to Chemical Analysis.*" Pp. 288. Bologna, 1944: C. Zuffi.

HIMUS G. W. "*The Elements of Fuel Technology.*" 8vo, pp. xvi + 506. Illustrated. London, 1947: Leonard Hill, Ltd. (Price 42*s.*).

JARVIS, E. G. and H. O. JARVIS. "*Facts for Foundrymen.*" Sixth Edition. 8vo, pp. ix + 79. Buffalo, N.Y., 1946: Niagara Falls Smelting and Refining Division, Continental-United Industries Co., Inc. (Price $1.00).

KAYE, G. W. C. and T. H. LABY. "*Tables of Physical and Chemical Constants.*" Tenth Edition, revised, 8vo, pp. 112. London, 1948: Longmans Green and Co., Ltd. (Price 21*s.*).

MORITZ, H. "*Spektrochemische Betriebsanalyse. Praktische Ratschläge für die Ausführung Spektrochemischer Analysen im Betriebslaboratorium.*" (Die Chemische Analyse, Bd. 43), 8vo, pp. xi + 170. Illustrated. Stuttgart, 1946: Ferdinand Enke. (Price 18.50 R.M.).

SIMONS, E. N. "*Iron Simply Explained.*" 8vo, pp. 203. London, 1947: Paul Elek. (Price 12*s.* 6*d.*).

SKYLLBERGS BRUKS AKTIEBOLAG. "*Skyllberg* 1346, 1646, 1946." Minnesskrift på uppdrag av Styrelsen för Skyllbergs Bruks Aktiebolag, utarbetad av Bertil Waldén. Första Delen. "*Tiden intill* 1775." 4to, pp. 326. Illustrated. Stockholm, 1947.

TOMASHOV, N. D. "*The Corrosion of Metals with Oxygen Depolarization.*" Pp. 258. Moscow, 1947: Acad. Sci. U.S.S.R. [In Russian].

TROESCHER, W. F. "*Hartverchromung im Werkzeug- und Machinenbau.*" Pp. 67. Berlin, 1947: Werkstatt und Betrieb.

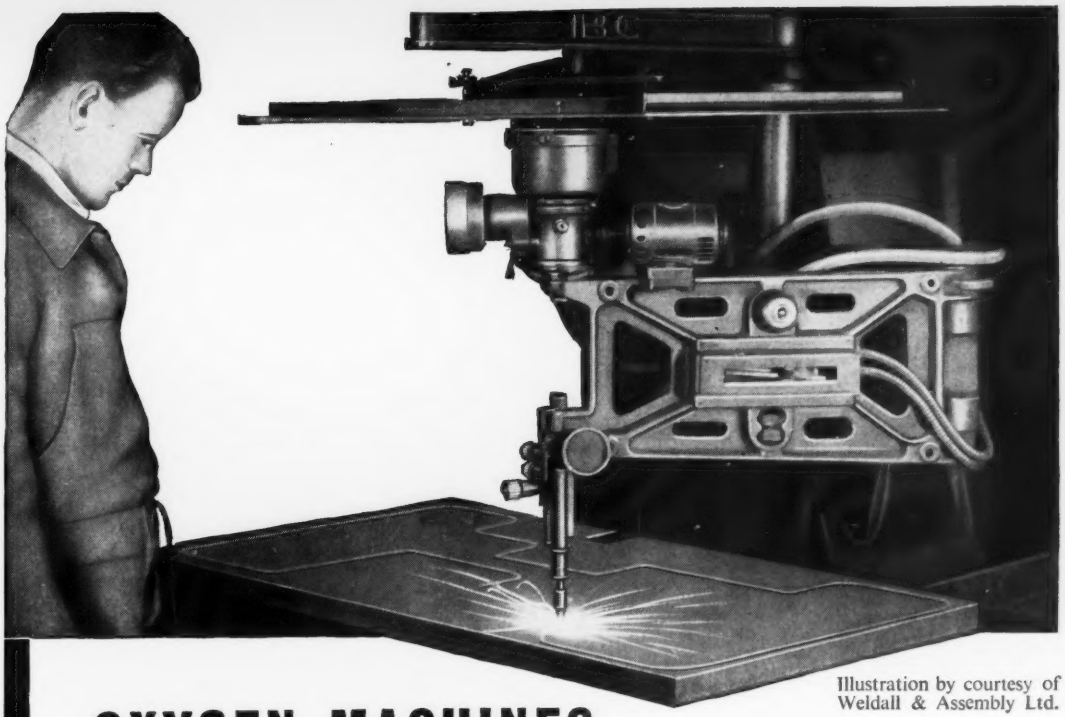
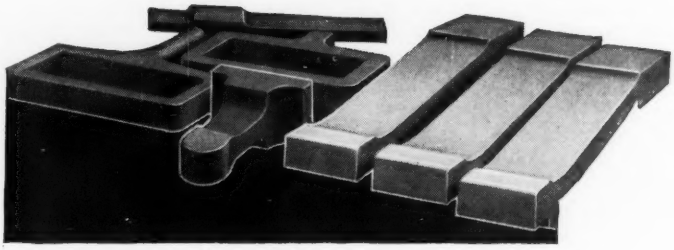


Illustration by courtesy of Weldall & Assembly Ltd.

OXYGEN MACHINES CUT A FINE FIGURE . . . FAST!

Oxygen cutting is much faster and more accurate than sawing, and will cut to thicknesses impossible to shear or guillotine. The illustration shows band saw bases being cut from mild steel plate 1½ inches thick, at a speed of some nine inches a minute.

For producing shapes in preparation for welding in steel fabrication, oxygen cutting machines are indispensable. Forgings, tubes, bars and other sections are cut as easily as steel plate. And because no shape is too complex to be handled, one profile machine can replace a number of mechanical operations—proof that the application of oxygen cutting to modern industry results in economical production at speeds which modern production schedules demand.



The components on the left show the type of work carried out by oxygen cutting machines at the British Railways' Wagon Works at Shildon.

For further details of Oxygen Cutting Machines, write for booklet TIB/8.

THE BRITISH OXYGEN COMPANY LTD.

BOC LONDON AND BRANCHES

BIF 1948
CASTLE BROMWICH
BIRMINGHAM
MAY 3-14
SEE OUR EXHIBIT
STAND No. D201

MARSHALL'S REFRACTORIES

Trumpet Bells, Guides and Bottom Guide Tubes form the tubular refractory lining of the cast iron casing, which guides the stream of molten metal from the ladle to the centre or distributor brick on its way to the ingot moulds.

Latest production methods and control ensure the right qualities in every piece. Continuous research and development to improve such products is part of our policy.

THOMAS MARSHALL & CO. (LOXLEY) LTD.
STORRS BRIDGE WORKS, LOXLEY,
Near SHEFFIELD.
PHONE SHEFFIELD 43844/5 GRAMS MARSHALL LOXLEY SHEFFIELD

"BITUMASTIC" SUPER SERVICE BLACK IS A heavy duty coating designed primarily for application to iron and steel surfaces.

One application only is necessary to provide a protective film three times the thickness of ordinary paint.

It can also be used successfully on wood, concrete and other porous materials after a priming coat of Standard Black "Bitumastic" Solution.

Tough and durable, "Bitumastic" Super Service Black affords an efficient protection against the destructive effects of industrial smoke, fumes and moisture-laden atmosphere.

Applied cold, straight from the drum, by brush only.

By using "Bitumastic" Super Service Black you will avoid repetitive painting and reduce maintenance costs.

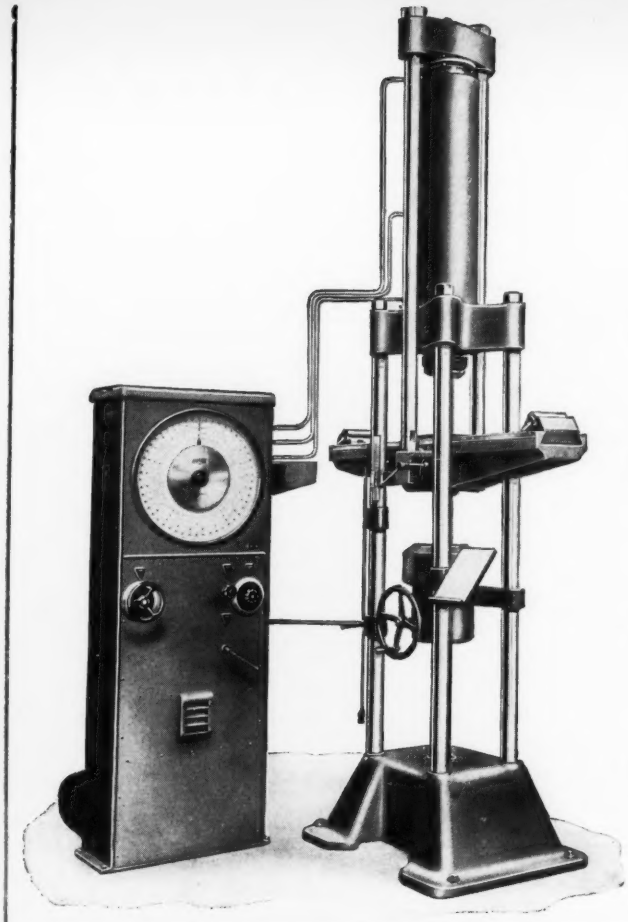
"Bitumastic" Super Service Black Solution is only one of the many specialised coatings manufactured by Wailes Dove Bitumastic Ltd.

Literature describing this and other "Bitumastic" products will be sent free and without obligation.

Write to-day for full particulars.

"BITUMASTIC" SUPER SERVICE BLACK SOLUTION

WAILES DOVE BITUMASTIC LIMITED · HEBBURN · CO. DURHAM
7HI4



Speedy and accurate testing for research and production purposes

The Avery Self-indicating Universal Testing Machine

No. 7102 CCH

CAPACITY 50 TONS

FEATURES

1. Four chart capacities: maximum, one half, one fifth, and one tenth of full capacity.
2. Large diameter charts.
3. Grouped controls for quick and easy operation.
4. Instantaneous capacity change.
5. No loose charts—no loose pendulum weights.

For full details of this machine, or of similar machines in different capacities, write for booklet T 2089.

In addition to the above type of testing machine, the Avery range comprises machines for hardness, impact and fatigue testing, dynamic balancing, etc.

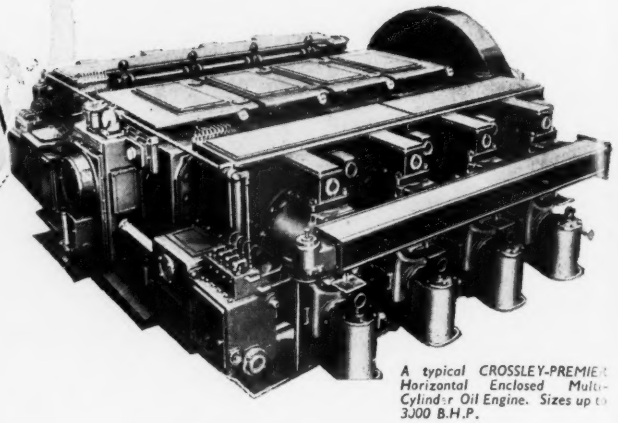
AVERY

W. & T. AVERY, LIMITED

SOHO FOUNDRY · BIRMINGHAM 40 · ENGLAND

7TH REPEAT ORDER
The Hoffman Mfg. Co. Ltd. CHELMSFORD
14TH REPEAT ORDER
Ashanti Goldfields Corpn. Ltd., GOLD COAST
12TH REPEAT
Lake View & Star Ltd., (New Consolidated Goldfields Ltd.) Australia.

No higher praise than REPETITION



A typical CROSSLEY-PREMIER Horizontal Enclosed Multi-Cylinder Oil Engine. Sizes up to 3000 B.H.P.

REPEAT ORDERS FOR 28,500 H.P. NOW IN HAND

Once a mine, quarry, oilfield, water undertaking, generating, station or industrial user has experienced the outstanding qualities of its first CROSSLEY-PREMIER ENGINE – then another and another CROSSLEY-PREMIER is the choice when additional power is required.

More than 130,000 H.P. in *repeat orders alone* have been received to date.

What more sincere tribute could there be to the rugged reliability of CROSSLEY-PREMIER Engines under the most arduous duties and difficult conditions?

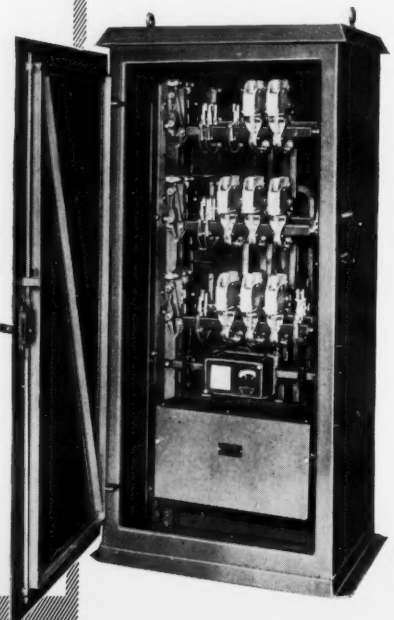
CROSSLEY - PREMIER ENGINES LTD.

SANDIACRE **NR. NOTTINGHAM**

London Office: Langham House, 308, Regent Street, W.1.

P69

A name increasingly specified

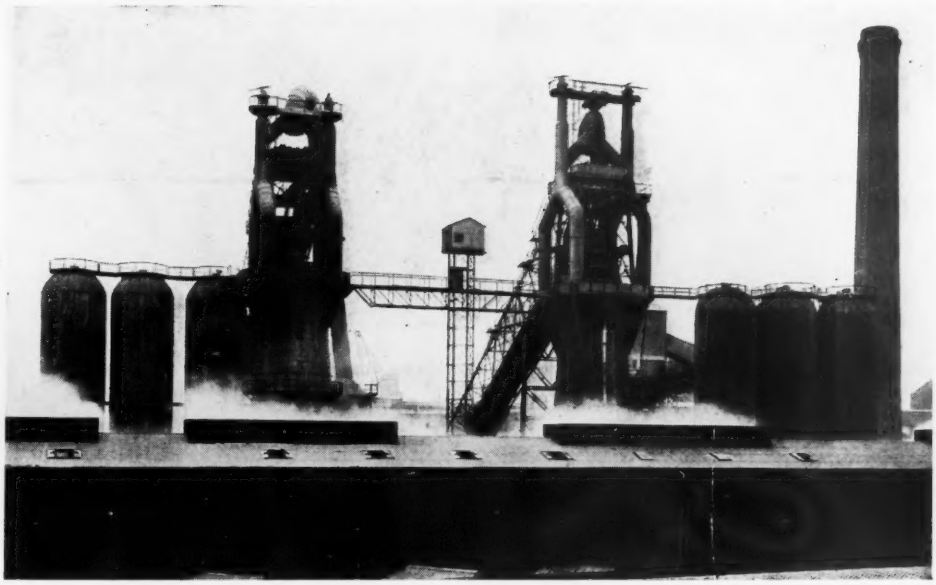


We manufacture a complete range of automatic starters for direct to line, star-delta, slipring, auto-transformer and direct current operation.

CONTACTOR SWITCHGEAR LTD.

WOLVERHAMPTON

CONSETT



PIG IRON

High Grade machine cast Hematite Pig Iron for Foundry and Steel making purposes. Approximate analyses and all other information given on application to the Company.

SIEMENS - MARTIN OPEN HEARTH STEEL
(Acid and Basic)

PLATES : For Ships, Tanks, Boilers, etc. To Lloyds, Admiralty, and all other standard specifications.

CHEQUERED PLATES : Admiralty 2″ x 1″ diamond pattern. Provide a hard-wearing non-slip surface for engine room and factory floors, etc.

SECTIONS : Angles, Bulb Angles, Channels, etc., for shipbuilding and structural engineering.

BLOOMS & BILLETS : Acid quality for forging, etc.

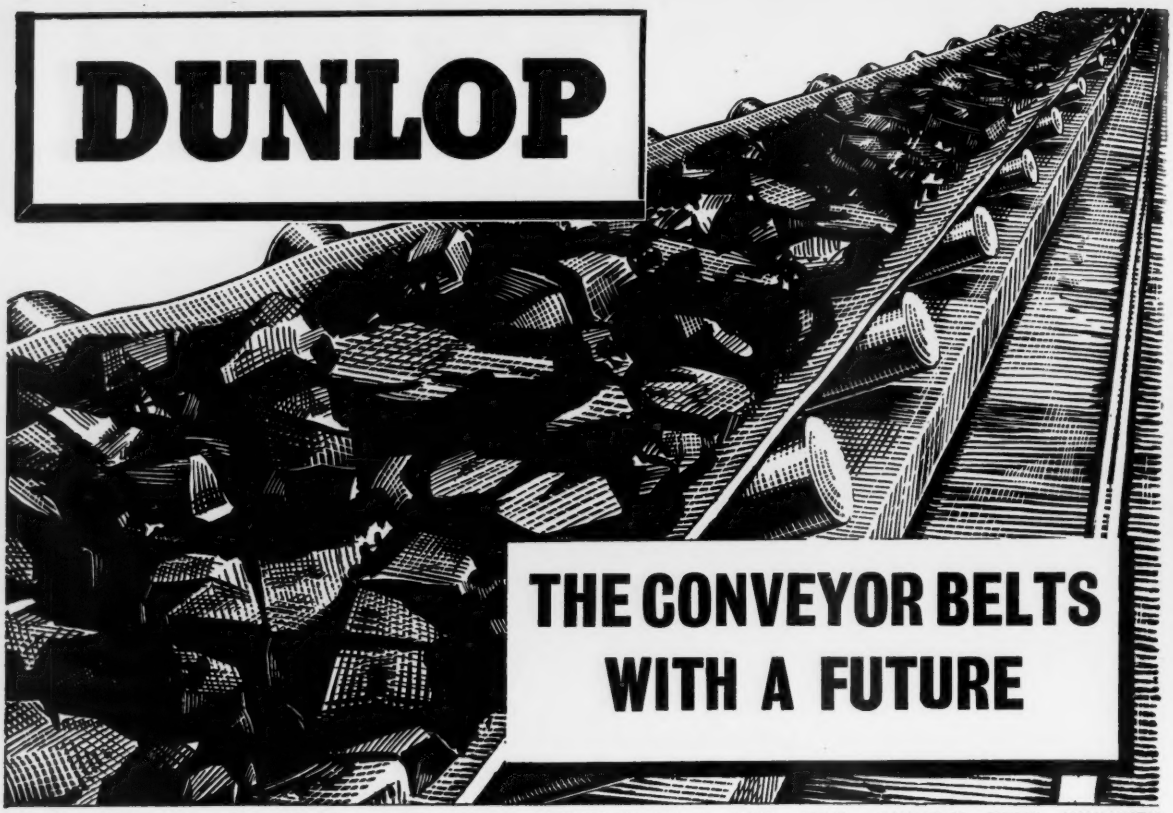
SPECIAL STEELS : Admiralty "D," "D.1," "D.W," etc. Copper-chrome ("CONICRO") high tensile steel. "BEARCO" copper-bearing corrosion-resisting steel.

REFRACTORIES

Silica, Magnesite, Chrome, Chrome Magnesite.
Bricks, Shapes and Cements for Steel Works and Carbonising Plants.

CONSETT IRON CO.
LIMITED
CONSETT · CO. DURHAM · ENGLAND
TELEPHONES : CONSETT 341 (10 LINES) TELEGRAMS : STEEL, PHONE, CONSETT

DUNLOP



THE CONVEYOR BELTS WITH A FUTURE

DUNLOP RUBBER CO. LTD. (GENERAL RUBBER GOODS DIVISION) WORKS & HEAD OFFICE: CAMBRIDGE STREET, MANCHESTER

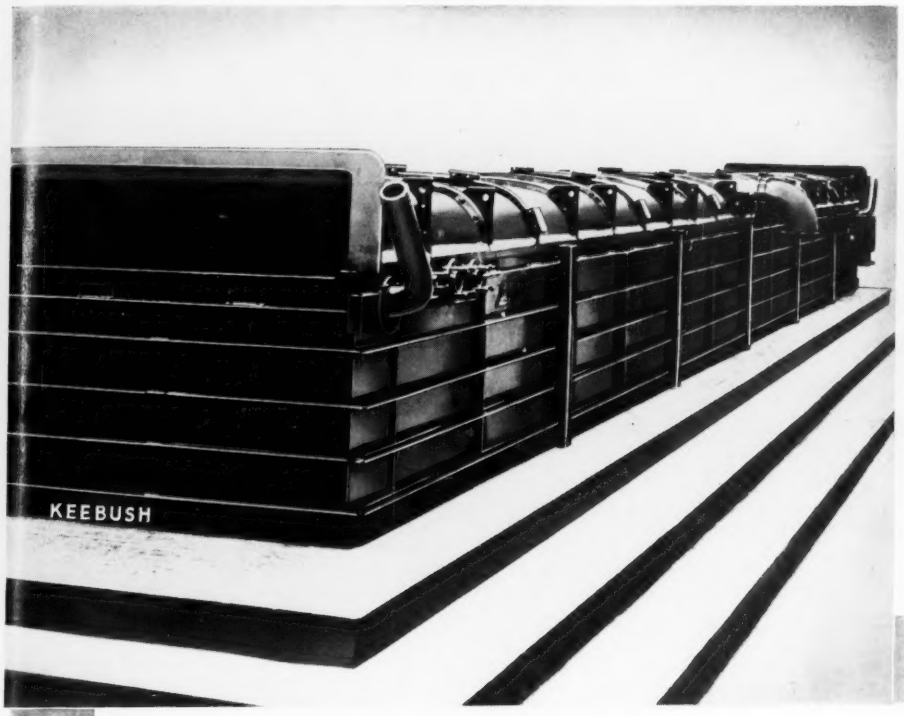
The matter is very urgent. Unless you can keep scrap moving back to us at shorter intervals, our steel production target for 1948 cannot be reached. Some of the scrap that the industry needs is in your yard. In every yard of every iron and steel user in Britain. Get the scrap moving and keep it moving. Call your scrap merchant up to the works today.

BRITISH IRON & STEEL

ISSUED BY THE BRITISH IRON AND STEEL FEDERATION

PICKLING PLANT

in **Keebush** *the unique acid resisting material*



KEE BUSH
TRADE MARK

This tank will be of interest to our friends in the Iron and Steel Industry as it is a strip pickling tank 60′ 0″ long made in six 10′ 0″ long sections. The cover is also constructed of Keebush and internally there are provided Keebush rollers mounted in Keebush bearings. We also provide a fan for the removal of fume on this unit.

STRIP PICKLING PLANT
WIRE PICKLING PLANT
TUBE PICKLING PLANT
STAMPINGS & FORGINGS PICKLING PLANT
BAR PICKLING PLANT
SHEET PICKLING PLANT

CONTINUOUS - SEMI-AUTOMATIC - BATCH
and the Kestner-Fahkler Acid Recovery Process

Auxiliary Plant :

PICKLING TANKS
FUME EXTRACT SYSTEMS
FANS
HOOKS
ROLLERS
BASKETS
STEAM INJECTORS
PUMPS
PIPE WORK & VALVES
CARBOY DISCHARGERS
ACID ELEVATORS
BULK ACID STORAGE
HEATING SYSTEMS
AGITATION SYSTEMS
NEUTRALISING PLANT
LIME AGITATORS
ACID SCRUBBING SYSTEMS

MOST OF THE ABOVE PLANT MANUFACTURED IN OUR KEEBUSH MATERIAL

Enquiries invited for all types of Pickling Plant : appropriate literature will be gladly sent without obligation

Kestner EVAPORATOR & ENGINEERING CO. LTD.

Chemical Engineers

5, GROSVENOR GARDENS, LONDON, S.W.I.

IRON POWDERS

('SINTREX' BRAND)

ELECTROLYTIC FOR POWDER METALLURGY

GREY CAST FOR CHEMICAL REDUCTIONS AND FLOOR HARDENING

ONE OF THE 600 GROUP OF COMPANIES

GEORGE COHEN, SONS & CO. LTD

BROADWAY CHAMBERS, LONDON, W.6 Telephone: Riverside 4141

482 IP.4/TJST

THE IRON AND STEEL INSTITUTE

4, GROSVENOR GARDENS, LONDON, S.W.1.

SYMPOSIUM ON POWDER METALLURGY

Second Impression

208 pages, with 259 illustrations and diagrams

Price: Members, 15s. *Non-Members, 25s.*

This book, No. 38 in the Special Report Series of The Iron and Steel Institute, has been thoroughly revised and a limited number of copies of the second, revised edition are now available.

The entire field of powder metallurgy is covered in 28 papers by acknowledged specialists.

SYMPOSIUM ON THE HARDENABILITY OF STEEL

430 pages, with 376 illustrations and diagrams

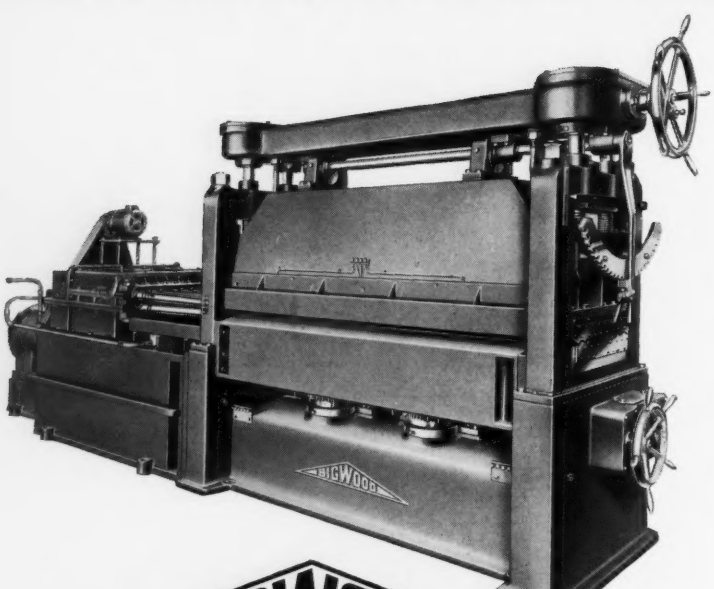
Price: Members, 15s. *Non-Members, 25s.*

This valuable book is now available as No. 36 in the Special Report Series of The Iron and Steel Institute. It contains a full account of investigations into the principle of The end-quench hardenability test, deals with the effects of alloying elements on hardenability, and the information which may be obtained from hardenability curves. Suggestions are made for future research.

Copies may be obtained by application to the Secretary, The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1.

WARDS for SIDINGS
To speed goods from factory to user is a problem of national importance to-day. The essential factor—the rapid handling and turn round of wagons—is dependent to a large extent on the efficient operation of sidings at the works and factories, at distribution points and, in most cases, at the bulk users' premises.
Well planned sidings cut transportation delays and pay for their cost in added efficiency and minimum maintenance charges—but the construction of sidings is emphatically a specialist's job.
For this reason we suggest you bring your railway problems to WARDS
The Railway Siding
Consultants and Contractors
THOS. W. WARD LIMITED
ALBION WORKS
'PHONE. 26311.
TWW
SHEFFIELD
'GRAMS "FORWARD"
London Office: BRETTENHAM HOUSE, LANCASTER PLACE, STRAND, W.C.I.

PRECISION ROLLER SHEET LEVELLING MACHINES



Bigwood's can offer precision roller sheet levelling machines to deal with thicknesses from 26 gauge up to $\frac{3}{8}$". The use of support rolls enables the work rolls to be kept to as small a diameter as the torque permits. Thus the machines operate satisfactorily on thin gauge material; the close spacing of the rolls and the wide range of possible roll adjustments allows the machine to deal with sheets in a single pass. The machine shown here is a 17 roll type R.L.P. Sheet Levelling Machine.

BIGWOOD

JOSHUA BIGWOOD & SON LTD., WOLVERHAMPTON

B 65

Dust Problems of Foundry and Smelting Plant

solved by

TRAUGHBER FILTERS

High efficiency filters for all sorts of dust produced in workshops, foundries and smelting plants.

●

Speciality:
Purification of air from sand blast, shot blast plants and grinding machines.

Capacity 40,000 c.f.m.

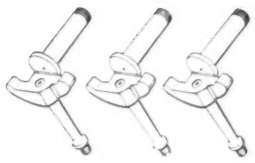
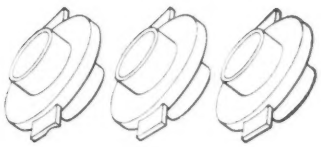
TELEPHONE 24771 (10 lines)

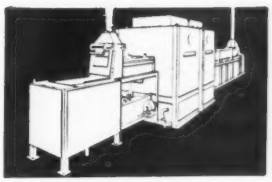
TRAUGHBER FILTER COMPANY LTD.

BIGWOOD WORKS · WEDNESFIELD RD. · WOLVERHAMPTON · ENGLAND

TF4

ELECTRIC FURNACE **brazing**

Automatic copper brazing by the BIRLEC  **method is ideal for building up components usually fabricated by welding, riveting or torch brazing.** **Cheaply produced pressings and capstan products can be built into complicated assemblies previously produced as a casting or forging.**  **With Birlec continuous brazing furnaces, successful results are assured, stronger and cheaper assemblies being rapidly and automatically produced.**



More details from our publication No. 57.

BIRLEC LTD · ERDINGTON · BIRMINGHAM 24

HEAT TREATMENT & MELTING FURNACES — BIRLEC

In Australia : Birlec Limited, Sydney, N.S.W. *In Sweden :* Birlec Elektrougnar AB, Stockholm

8a.48

EUROPE AFRICA AMERICA AUSTRALIA ASIA

Export has become a science in itself. We possess a specialized knowledge and we keep abreast of rapidly changing conditions by day to day practice. You manufacture — we export : let us co-operate in the Export Drive.

Our customers abroad are waiting to increase imports from this country.

Our Agents overseas are keeping us well informed about trade developments everywhere.

Our buying and selling staff at home are readily prepared to put their knowledge and experience at your disposal.

Our services include, if desired, packing, warehousing, forwarding, insuring and shipping the goods.

Our suppliers can determine whether they wish us to act as principals or selling agents or sole distributors.

Our travelling representatives are continuously engaged in maintaining personal contact with prospective buyers and official quarters.

Our terms of payment are cash when the goods are ready.

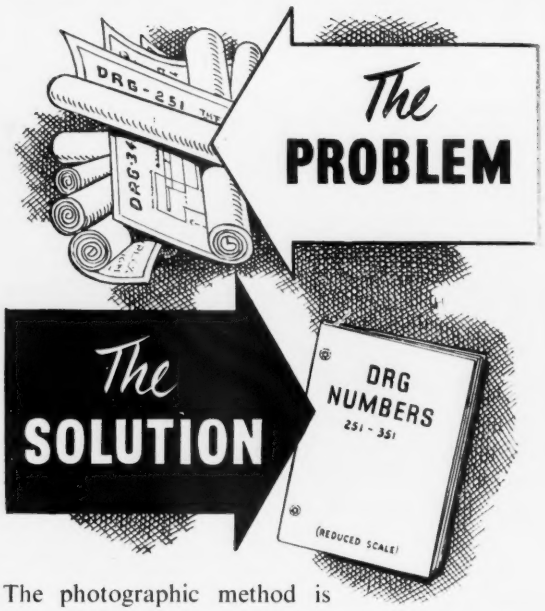
Our organisation is well equipped to carry out every task entrusted to us.

FROM YOUR FACTORY TO OUR CUSTOMERS ALL OVER THE WORLD

We invite your enquiries and our booklet " Export Advice " will gladly be sent on request.
If desired, one of our Executives will be available for personal conversation at any time and anywhere in this country.

BRITISH TRADERS & SHIPPERS, LTD.
155, FENCHURCH STREET, LONDON, E.C.3

Telephone : Mansion House 1603 (18 Lines)
Telegrams: Shipex, Fen, London



The photographic method is the answer to your storage problem. Plans, blue prints and drawings can be copied down to a considerably reduced scale and compactly filed away for future reference. Photographic reproduction on Ilford Document Papers is unequalled for clarity, giving the maximum visible contrast, i.e., strong black images combined with clear whites. Ilford Document Papers are made on a special thin, tough base and can if necessary be folded and creased without cracking or damaging the sensitised coating.

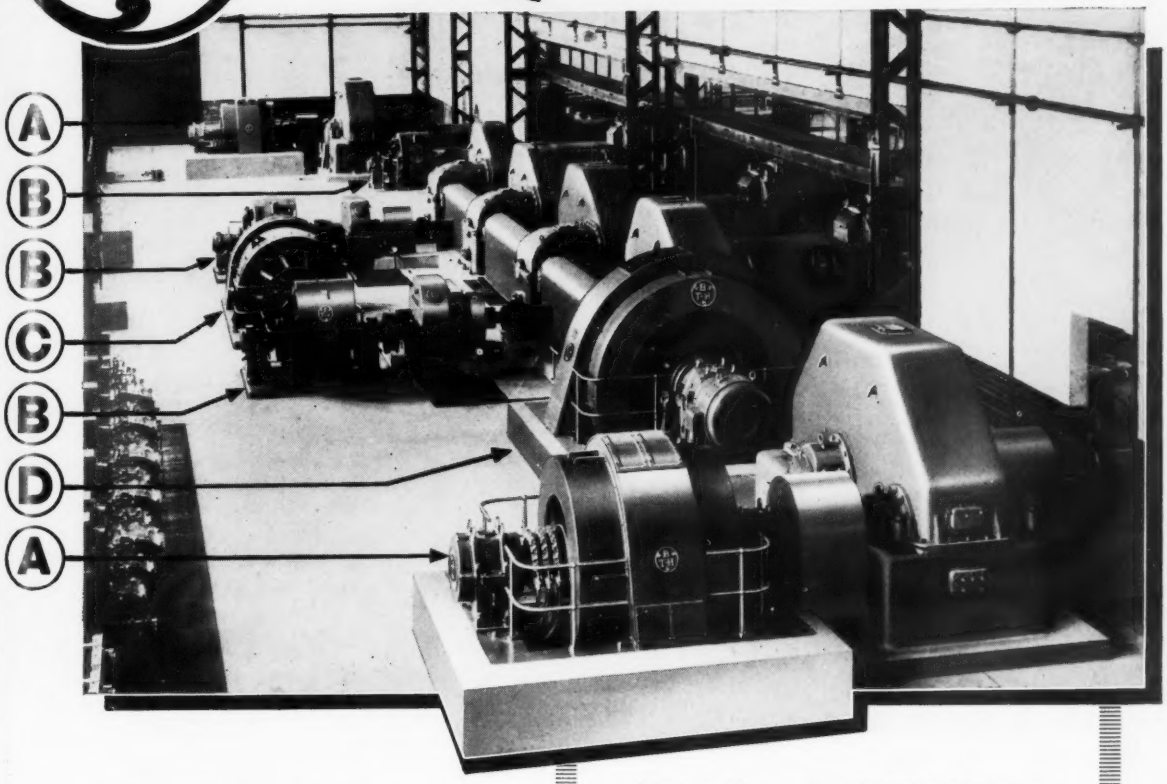
The Ilford Technical Service is at your disposal to advise on any problems connected with photographic reproduction.

ILFORD
Document Papers

ILFORD LIMITED · ILFORD LONDON

B T-H

ROLLING MILL EQUIPMENT



Rolling Mills of all types and sizes, in this country and overseas, are being driven by BTH Electrical Equipment

Profit by this experience and send us your enquiries

Motor House for 24″ Continuous and Tandem Billet Rolling Mills

A — Two 4,000 H.P. Peak, 495 r.p.m., Slip-ring Induction Motors driving Tandem Billet Rolling Mill.

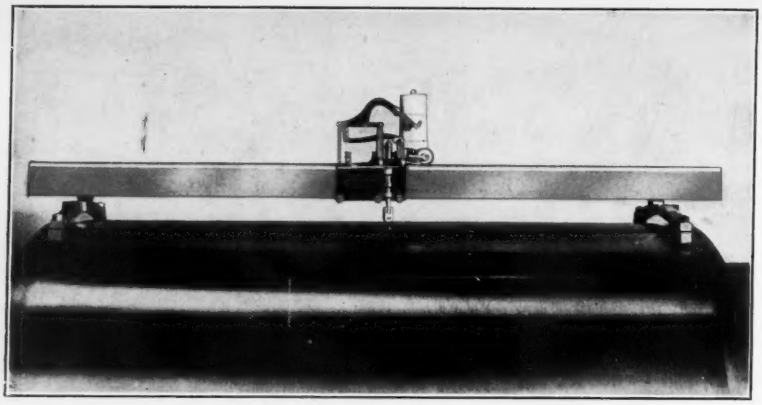
B — Three 1,000 H.P. Peak, 360/720 r.p.m., D.C. Motors driving Edging Stands of Billet Mills.

C — 1,500 K.W. Synchronous Motor-generator set for supplying the Edging Stand Motors.

D — 9,000 H.P. Peak, 300 r.p.m., Type A M T, Synchronous-induction Motor (0.95 leading power factor) driving Continuous Billet Rolling Mill.

BTH RUGBY

THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, RUGBY, ENGLAND. A3119N



for

LONGER LIFE OF ROLLS

◆

UNIFORM SUBSTANCE SHEETS & STRIP

- *Experts advise* "**Determine a camber** that suits the product and can be readily modified."
  "The contour must be **related to Mill Practice,** particularly in regard to draft."
- *Therefore* Check and record the surface condition and contour of your rolls after use and again after each dressing,

with a

GILBERTSON-THOMAS ROLL CAMBER RECORDER

Sole and Distributors Exporters BRITISH & CONTINENTAL TRADERS LTD · Bank Chambers, 329, High Holborn, London, W.C.1

TO THE TRADE

Electro deposition of all metals.
Ceramic coatings for Steel.

METAL FINISHING

DESIGN and INSTALLATION of PLANT FOR ALL PROCESSES

Rushclene Descaler for Iron & Steel
Rushtol Chemicals for Electro-deposition
Polishing and Finishing Mops

GUARANTEED SERVICE AGREEMENTS

THE RUSHTON ORGANISATION LTD.

38-41 Woburn Place, W.C.1 · Phone : MUSeum 3161

Roundhay Road, Leeds 8 - Rio de Janeiro - Matunga, Bombay.

THE IRON AND STEEL INSTITUTE

4, Grosvenor Gardens, London, S.W.1.

REVISED PRICE LIST OF PUBLICATIONS

(as from 1st May, 1948).

	Published Price	Members' Rate	Libraries and Technical Societies	Booksellers' Rate
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1. Monthly Journal (1947 onwards).				
Subscription rate per annum. (Binding case and index free on request) ...	5 0 0	3 0 0	4 3 4	4 3 4
Postage	8 0	8 0	8 0	8 0
Single issues	10 0	7 6	8 4	8 4
Postage	8	8	8	8
2. Bound Volumes (1947 onwards).				
Subscription rate per annum (3 volumes)	5 0 0	3 0 0	4 3 4	4 3 4
Postage	2 3	2 3	2 3	2 3
Single volumes	2 0 0	1 0 0	1 13 4	1 13 4
Postage	9	9	9	9
3. Journal (up to and including 1946).				
Per volume	2 0 0	1 0 0	1 13 4	1 13 4
4. Carnegie Scholarship Memoirs (up to and including 1938).				
Per volume	16 0	10 0	13 4	13 4
5. Special Reports.				
(a) Second Ingot Report; Nos. 1, 2, 5, 8, 9, 13, 14, 16, 21, 24, 25, 26, 28, 30, 32, 33, 35, 36, 37, 38	1 5 0	15 0	1 0 0	1 0 0
(b) First and Third Ingot Reports; Nos. 3, 4, 6, 7, 10, 15, 17, 18, 20, 22, 23, 27, 29, 34	15 0	7 6	12 6	12 6
(c) Nos. 19, 31	7 6	3 9	6 3	6 3
(d) Nos. 11, 12	No charge	No charge	No charge	No charge
6. Indexes.				
1869–1881; 1882–1889; 1869–1896; 1890–1900; 1901–1910; 1911–1921; 1922–1931				
Per volume	16 0	10 0	13 4	13 4
7. Bibliographies.				
Per copy	2 6	1 3	2 0	2 0
8. Reprints of Papers printed in the Journal (up to 1946 only).				
Per copy	2 6	1 3	2 0	2 0

"EXTRA HEAVY DUTY REQUIRES B.F. 954, THE SUPER WEAR-RESISTING ALLOY IRON"

in B·F·954

The "SUPER" WEAR-RESISTING ALLOY IRON

B.F. 954 is a Super wear-resisting alloy iron having hard martensitic characteristics. It possesses a toughness considerably in excess of that of white irons and unannealed malleable iron. It is an electric furnace product produced under conditions of strict scientific control, and castings up to one ton individual weight are manufactured.

B.F. 954 has, on test, proved itself the long lasting, trouble-free material for
LINING PLATES FOR BALL & TUBE MILLS – PUG MILL RINGS – HOOPS & KNIVES – CRUSHER JAWS – GUIDE PLATES – CHEEK LINERS & CONES – SAND & SHOT BLAST MACHINERY NOZZLES – BLADES, ETC.

Technical advice and assistance readily given

BRADLEY & FOSTER LIMITED

DARLASTON - STAFFS

Telephone: Darlaston 353 (5 lines)

Index to Advertisers

Acheson, E. G., Ltd. — —
Ashmore, Benson, Pease & Co., Ltd. — *Inside back cover*
Avery, W. & T., Ltd. — 37

Bigwood, Joshua, & Son, Ltd. — 44
Birlec, Ltd. — 45
Blaw-Knox, Ltd. — 27
Bradley & Foster, Ltd. — 50
Brightside Foundry & Engineering Co., Ltd., The — 13
Bristol's Instrument Co., Ltd. — 22
British & Continental Traders, Ltd. — 48
British Gas Council — —
British Iron & Steel Federation, The — 40
British Oxygen Co., Ltd. — 35
British Rollmakers Corporation, Ltd. — 6
British Steel Founders' Association — —
British Thomson-Houston Co., Ltd. — 47
British Timken, Ltd. — —
British Traders & Shippers, Ltd. — 46
Brockhouse, J., & Co., Ltd. — —
Bushing Co., Ltd., The — 22

Cargo Fleet Iron Co., Ltd. — 4
Chesterfield Tube Co., Ltd., The — 25
Climax Molybdenum Company of Europe, Ltd., The — 8
Cochran & Co. (Annan), Ltd. — —
Cohen, George, Sons & Co., Ltd. — 42
Colvilles, Ltd. — —
Consett Iron Co., Ltd. — 39
Contactor Switchgear, Ltd. — 38
Crossley-Premier Engines, Ltd. — 33

Davy & United Engineering Co., Ltd. — *Inside front cover*
Dolomite Brickmakers Association — 24
Dunlop Rubber Co., Ltd. — 40

Electric Furnace Co., Ltd. — 30
Electroflo Meters Co., Ltd. — —
Elliott Bros. (London), Ltd. — —
English Electric Co., Ltd., The — —
English Steel Corporation, Ltd. — 34

Fescol, Ltd. — 15
Firth-Vickers Stainless Steels, Ltd. — —
Fordath Engineering Co., Ltd. — —
Foster, Henry, & Co., Ltd. — —

General Electric Co., Ltd., The — 23
General Refractories, Ltd. — —
Gibbons Brothers, Ltd. — 21
Glenboig Union Fire Clay Co., Ltd. — —
Guest Keen Baldwins Iron & Steel Co., Ltd. — 29

Hallamshire Steel & File Co., Ltd., The — 26
Head, Wrightson & Co., Ltd. — —
Head, Wrightson Machine Co., Ltd. — 18

Igranic Electric Co., Ltd. — —
Ilford Ltd. — 46
Imperial Chemical Industries, Ltd. — —
Incandescent Heat Co., Ltd., The — —
International Construction Co., Ltd., The — 17

Kent, George, Ltd. — —
Kestner Evaporator & Engineering Co., Ltd. — 41

Lamberton & Co., Ltd. — *Outside back cover*
Lee, Arthur, & Sons, Ltd. — —
Lloyd, F. H., & Co. Ltd. — 20
Loewy Engineering Co., Ltd., The — 28

Marshall, Thomas, & Co. (Loxley) Ltd. — 36
Metallisation, Ltd. — —
Metropolitan-Vickers Electrical Co., Ltd. — —
Mills, Exors. of James, Ltd. — 10
Ministry of Fuel and Power — —
Mond Nickel Co., Ltd. — —
Morgan Crucible Co., Ltd., The — —
Murex Ltd. — —
Murex Welding Processes, Ltd. — —

Newton, Chambers & Co., Ltd. — —

Permutit Co., Ltd., The — 7
Philips Industrial (Philips Lamps, Ltd.) — 3
Priest Furnaces, Ltd. — 19

Remington Rand, Ltd. — —
Robertson, W. H. A., & Co., Ltd. — 11
Rushton Organisation Ltd., The — 49
Ruth's Accumulators (Cochran), Ltd. — —

Sanderson Bros. & Newbould, Ltd. — —
Schori Metallising Process, Ltd. — —
Siemens-Schuckert (Gt. Britain), Ltd. — —
Simon-Carves, Ltd. — 9
Stanton Ironworks Co., Ltd., The — —
Steel Company of Wales, Ltd., The — 2
Stein & Atkinson, Ltd. — —
Stein, John G., & Co., Ltd. — —

Tinsley (Industrial Instruments) Ltd. — 16
Traughber Filter Co., Ltd. — 44

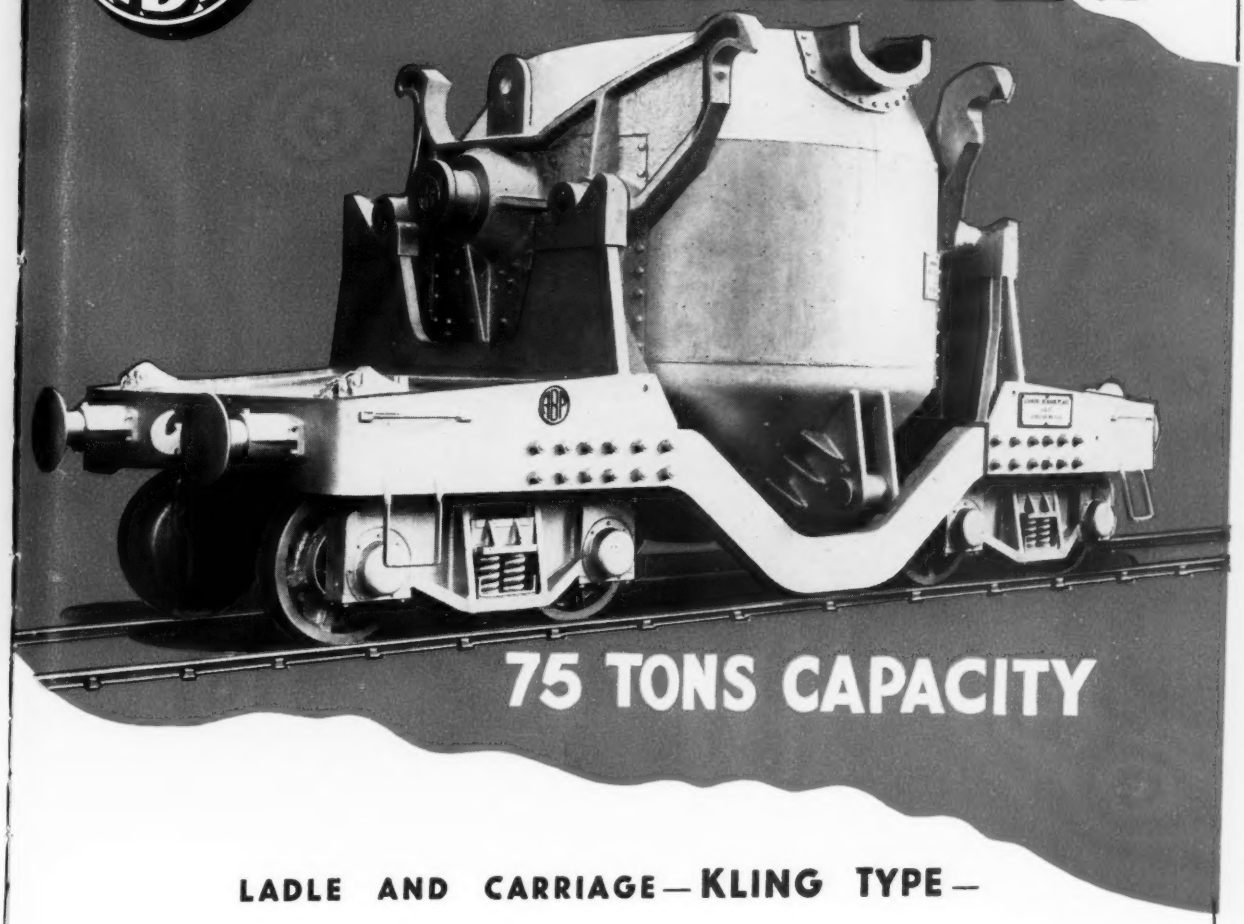
United Steel Companies, Ltd., The — 32

Vaughan Crane Co., Ltd., The — 26

Wailes Dove Bitumastic, Ltd. — 36
Ward, Thos. W., Ltd. — 43
Wellman Smith Owen Engineering Corporation, Ltd., The — 1
Whitehead Iron & Steel Co., Ltd. — 12
Wincott, G. P., Ltd. — 14
Woodall-Duckham Vertical Retort & Oven Construction Co. (1920), Ltd., The — 5
Wright Anderson & Co., Ltd. — —

Published at the offices of the Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, and Printed in Great Britain by HARRISON & SONS LTD., Printers to His Majesty The King, London, Hayes (Middx.) and High Wycombe

HOT METAL LADLES



75 TONS CAPACITY

LADLE AND CARRIAGE—KLING TYPE—

RAIL GAUGE	4′-8½″
OVERALL LENGTH	26′-0″
MAX. HEIGHT	11′-6″
MAX. WIDTH	11′-5″

ASHMORE, BENSON, PEASE & CO., LTD.

STOCKTON-ON-TEES ENGLAND

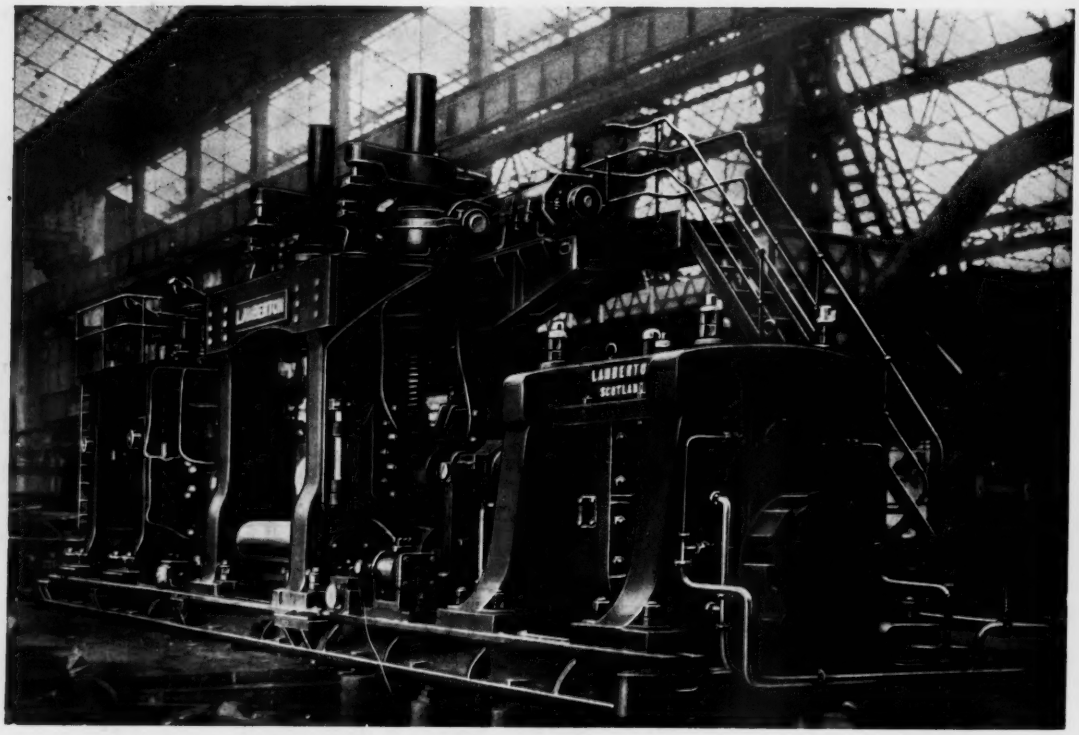
AND LONDON, AUSTRALIA, CANADA, INDIA, SOUTH AFRICA

A-HML

LAMBERTON

Rolling Mill Plant Manufacturers

COATBRIDGE - SCOTLAND



2-STAND REVERSING MILL

for producing Channels, Angles, Flats, Squares, Rounds, etc.

Designed & built by us with all roller tables manipulators shears and auxiliaries and supplied to customer complete with electrical equipment.

1033 43

es
ed
t.